# The Journal of Bone and Joint Surgery

*The Official Publication of*
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association

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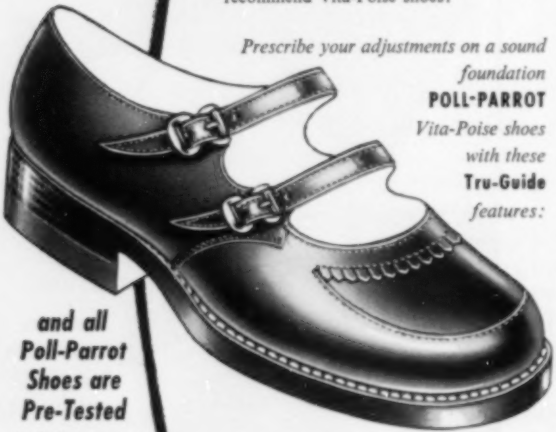

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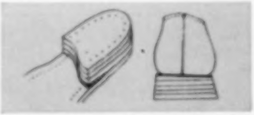

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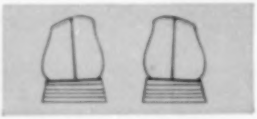

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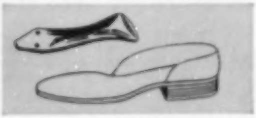

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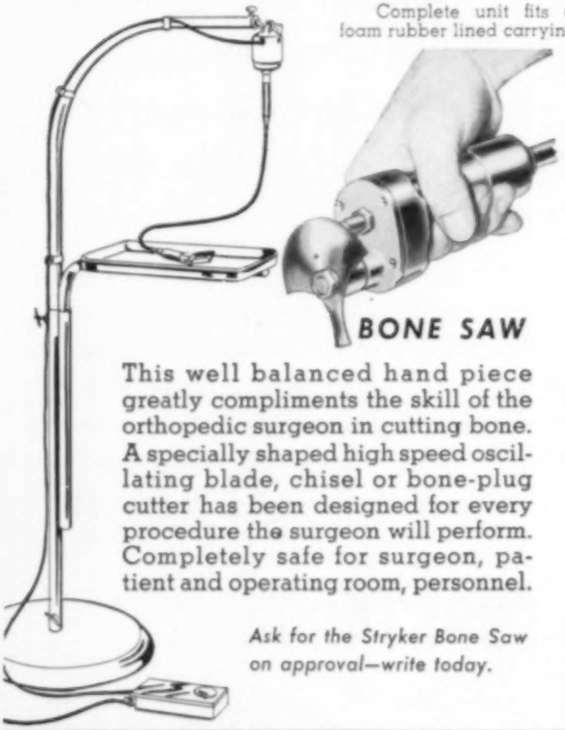

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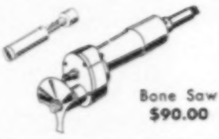

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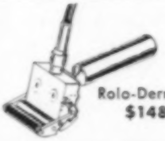

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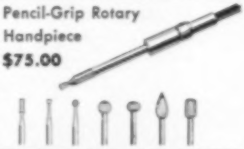

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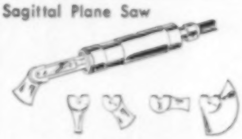

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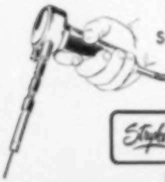

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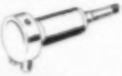

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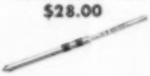

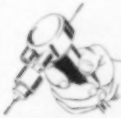

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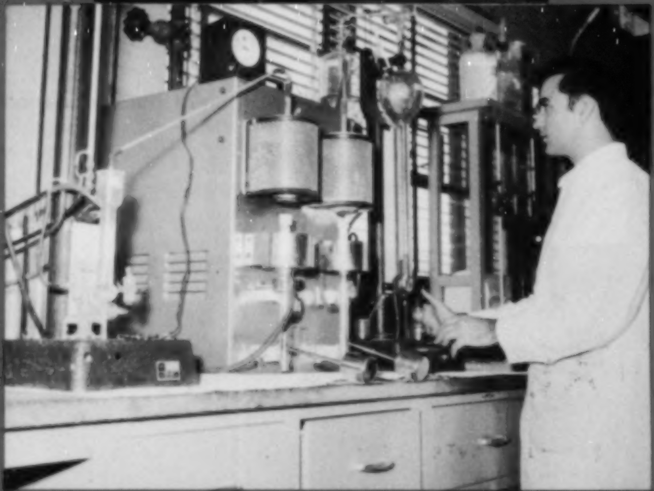

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- Only those Vitallium appliances designed to replace an articulating surface are highly polished for smoother function.
- The familiar satin finish on Vitallium appliances reduces glare from operating room lights.
- Vitallium appliances have proved to be compatible with, and completely inert in, human tissue.
- In 22 years of use, over 7 million Vitallium appliances have been surgically implanted.
- There has never been one authenticated case of corrosion reported where a Vitallium appliance has been used.
- Vitallium appliances may be used together in the same patient without electrolytic reaction or ill effect.
- Vitallium appliances are X-rayed for internal soundness and surface inspected by the Zyglo† penetrant method.
- Vitallium Surgical appliances merit the confidence of surgeons.

†Tr. Mk. of Magnaflux Corp.

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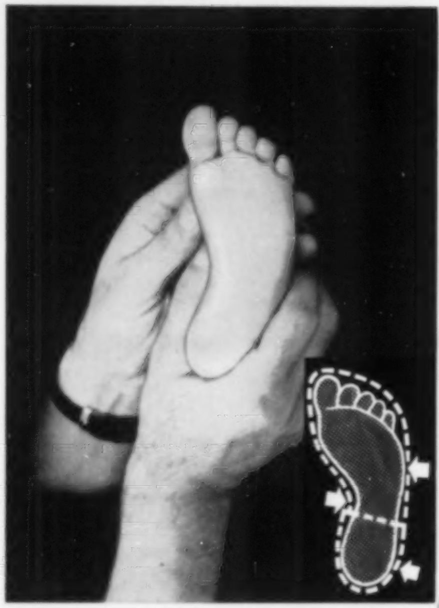
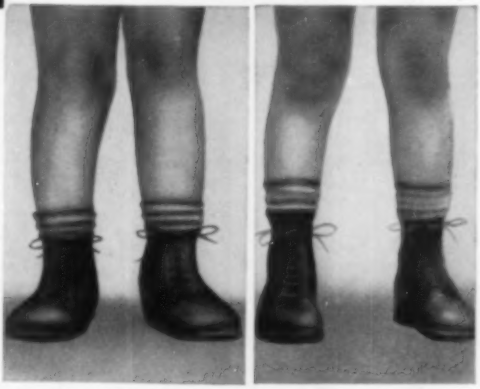
# the action of the TARSO SUPINATOR SHOE

. . . swings the hind-foot inward, which induces adduction of the fore-foot, elevates the longitudinal arch, and levels the ankle joint.

When the hind-foot is held in a position of inward rotation, the talo-scaphoid and cuneiform-scaphoid joints will remain locked under weight bearing. The arch will not collapse and the ankle will not roll inward.

Correction is accomplished by the specially shaped last. Medially wedged and extended heels promote better weight distribution. Medially extended counters are used for utmost control.





**BEFORE** **AFTER**

The Tarso Supinator shoe is used successfully in treatment of the plano-valgus foot. Pronation is controlled at once. Permanent improvements in walking and in foot posture will generally occur. Patients find Tarso Supinators notably comfortable.

Tarso Shoes are ready-made and are available on prescription from dealers in most cities. Write for catalog and name of nearest dealer.

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Tarso shoes have been in use for over twenty-five years.

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SMO STAINLESS

Richards diamond intramedullary pins offer the surgeon an aid in the prevention of rotation of fragments.

Flexible in the minor diameter, yet rigid in the major diameter, the diamond cross-sectional shape adapts to the contour of the intramedullary canal, yet provides excellent internal fixation.

**PRICE PER SET INCLUDES ALUMINUM RACK**

**No. 203** Set 7mm x 9mm diameter pins for the FEMUR.
9 pins from 11" to 17" ........ $67.50
Individual pins as follows ........ each 7.50

| A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|
| 11" | 11¾" | 12½" | 13¼" | 14" | 14¾" | 15½" | 16¼" | 17" |

**No. 204** Set 4mm x 6mm diameter pins for TIBIA, HUMERUS AND LOWER THIRD OF FEMUR.
9 pins from 8" to 14" ........ $54.00
Individual pins as follows ........ each 6.00

| A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|
| 8" | 8¾" | 9½" | 10¼" | 11" | 11¾" | 12½" | 13¼" | 14" |

**No. 205** Set 3mm x 5mm diameter pins for HUMERUS.
9 pins from 8" to 14" ........ $54.00
Individual pins as follows ........ each 6.00

| A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|
| 8" | 8¾" | 9½" | 10¼" | 11" | 11¾" | 12½" | 13¼" | 14" |

**No. 206A** Set 3mm x 5mm diameter pins for RADIUS AND ULNA.
13 pins from 4" to 10" ........ $52.00
Individual pins as follows ........ each 4.00

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4" | 4½" | 5" | 5½" | 6" | 6½" | 7" | 7½" | 8" | 8½" | 9" | 9½" | 10" |

**No. 206B** Set 2mm x 3mm diameter pins for RADIUS AND ULNA.
13 pins from 4" to 10" ........ $52.00
Individual pins as follows ........ each 4.00

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4" | 4½" | 5" | 5½" | 6" | 6½" | 7" | 7½" | 8" | 8½" | 9" | 9½" | 10" |

**No. 207** Set 2mm x 3mm pins for PHALANGES AND SMALL BONES.
13 pins from 1" to 4" ........ $26.00
Individual pins as follows ........ each 2.00

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1" | 1¼" | 1½" | 1¾" | 2" | 2¼" | 2½" | 2¾" | 3" | 3¼" | 3½" | 3¾" | 4" |

## HAND PIN INSERTER

FOR EITHER ROUND OR DIAMOND PINS

Anodized aluminum to prevent scratching or nicking pins. Thumb screw holds pin in place to gently introduce pin by hand. Not to be used as a driver. One size, 3/16" slot, takes any round pin 3/16" D. or smaller, and both the 2mm x 3mm and 3mm x 5mm diamond pins.

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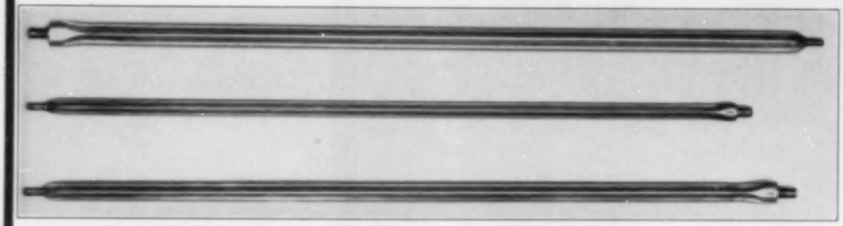
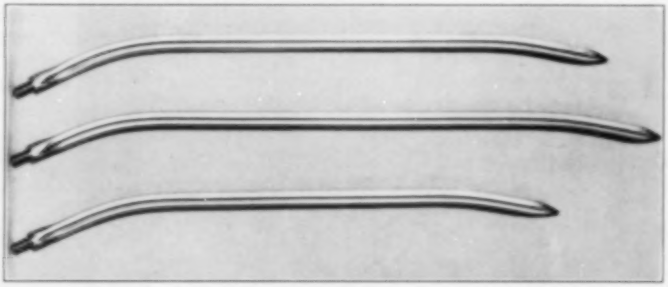
# *LOTTES* NAILS and INSTRUMENTS



***LOTTES* FEMORAL NAILS** are manufactured with diameters of 3/8, 7/16, and 1/2 inches—with lengths in 1/2 inch sizes from 14 to 20 inches.

***LOTTES* TIBIAL NAILS** are made in 5/16 and 3/8 inch diameters—in lengths from 9 to 15 1/2 inches, also in 1/2 inch sizes.



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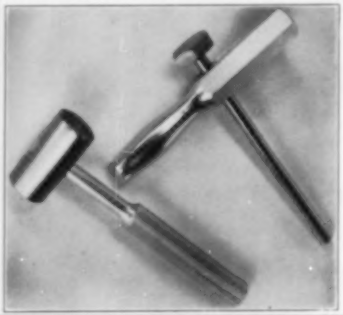

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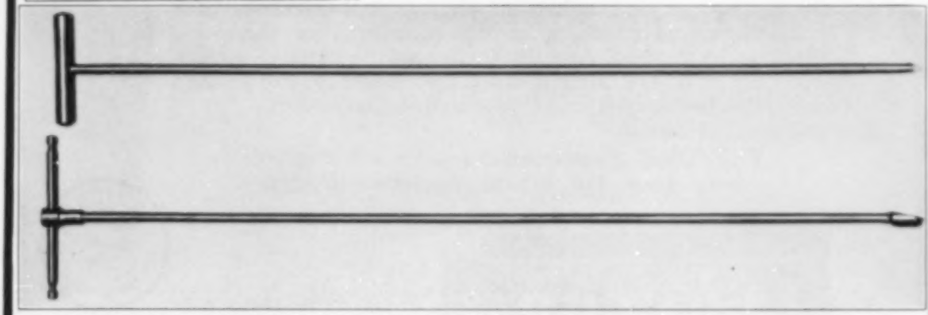

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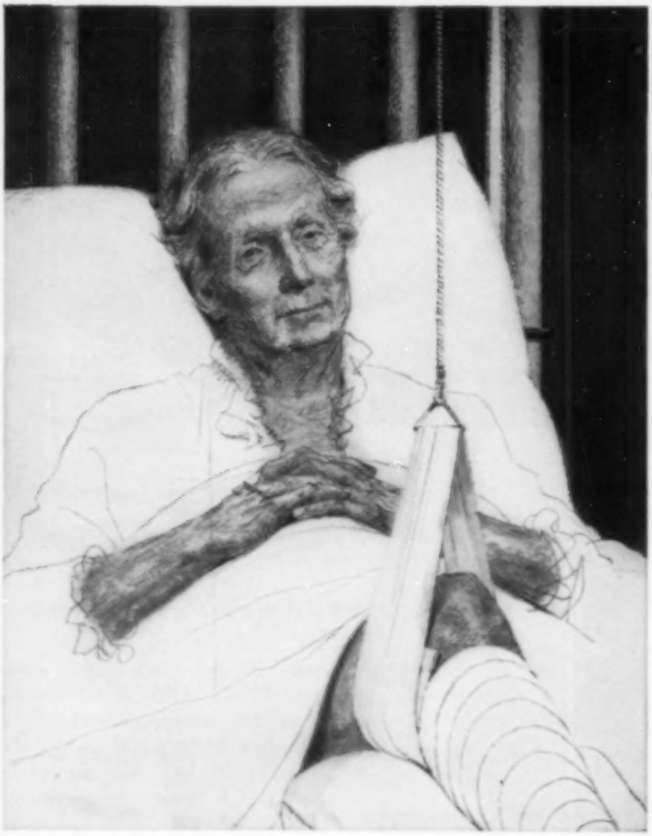

*weeks?*

*months?*

*years?*

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Healing of fractures is often delayed because impairment of osteoblastic activity due to declining sex hormone function causes the bone matrix to atrophy.

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*Reifenstein, E. C., Jr., in Harrison, T. R.: Principles of Internal Medicine, ed. 2, New York, The Blakiston Company, Inc., 1954, chap. 98, pp. 702, 703.

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**FLOATING TONGUE!**

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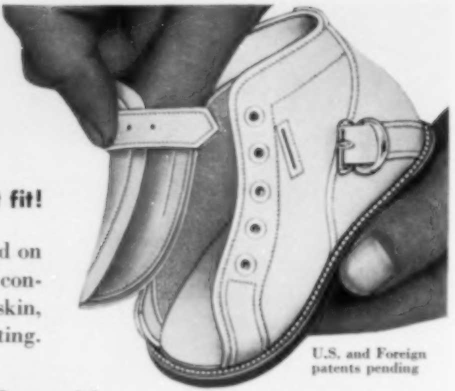

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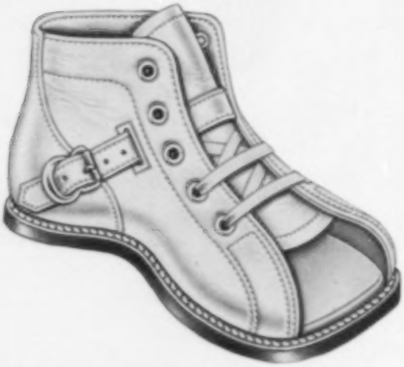

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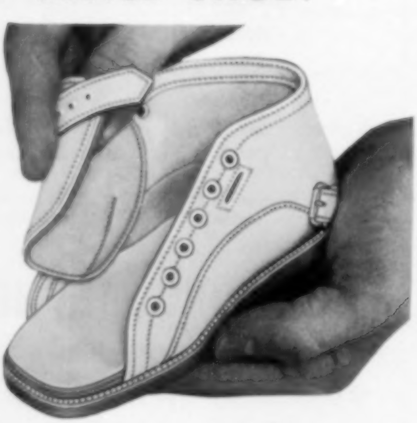
- **REINFORCED SIDE ARCHES COMPENSATE FOR REMOVED COUNTERS**
- **FLOATING TONGUE LETS YOU *SEE* PROPER FIT!**

* Including congenital talipes equino-varus, congenital calcaneovalgus, cerebral palsy (spastic paralysis), congenital subluxation or dislocation of the hips, bow legs and knock knees.



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This Spencer Support, individually designed to reduce forward flexion and scoliosis, accomplishes the following . . .

- Provides brace-type hyperextension with a reinforced panel extending from pubis to sternum.
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CAST SPREADER

*featuring* Thin Interdigitated Teeth

***Check these features:***

Simply squeeze and the interdigitated teeth spread the cast.

The teeth are of special steel alloy hardened to prevent bending or breaking.

Rounded guard keeps blade from advancing into plaster to pinch skin.

**In addition to the No. 82 office model (pictured), a heavy duty, 19½ inch long Model No. 83 is available.**

**Combination price for Models 82 and 83 . . . . . . . . $45.00**

**Both Models 82 and 83**
**$24.50 ea.**

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Orthopedic Frame Company

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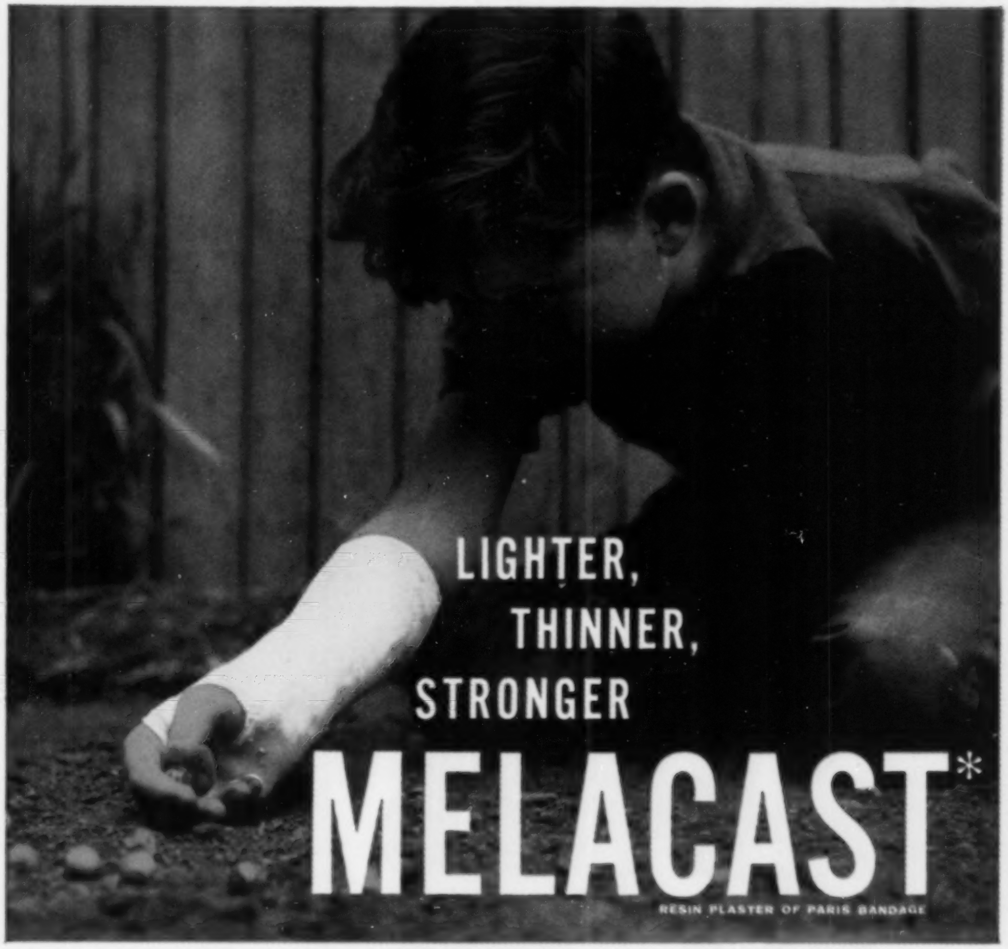

**ready to use** just dip, squeeze and apply...requires half as many bandages as ordinary plaster casts

**correct drying action** no waiting...allows trimming time, then hardens to full strength promptly

**makes more comfortable, better looking casts** lighter, thinner, smoother...yet much stronger than heavier, clumsier casts of ordinary plaster

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**costs less per cast than plain plaster** Specify modern, easier-to-use MELACAST in the new plastic-lined, moisture-proof package...another outstanding SPD development.

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*Producers of Davis & Geck Brand Sutures*
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Fifty-seven years of craftsmanship go into the making of **Edwards** Pedic shoes, the only complete line of children's prescription shoes in America. Ideal for lateral or medial wedging, **Edwards** Pedics are made on tested lasts, from clinic-approved patterns. Write for the name of your nearest **Edwards** dealer, who is trained in prescription fitting, and for a Pedic brochure.

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REVERSE LAST

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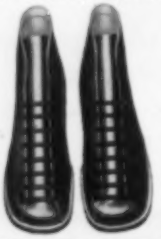

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*Precise Positioning and Positive Fixation—*

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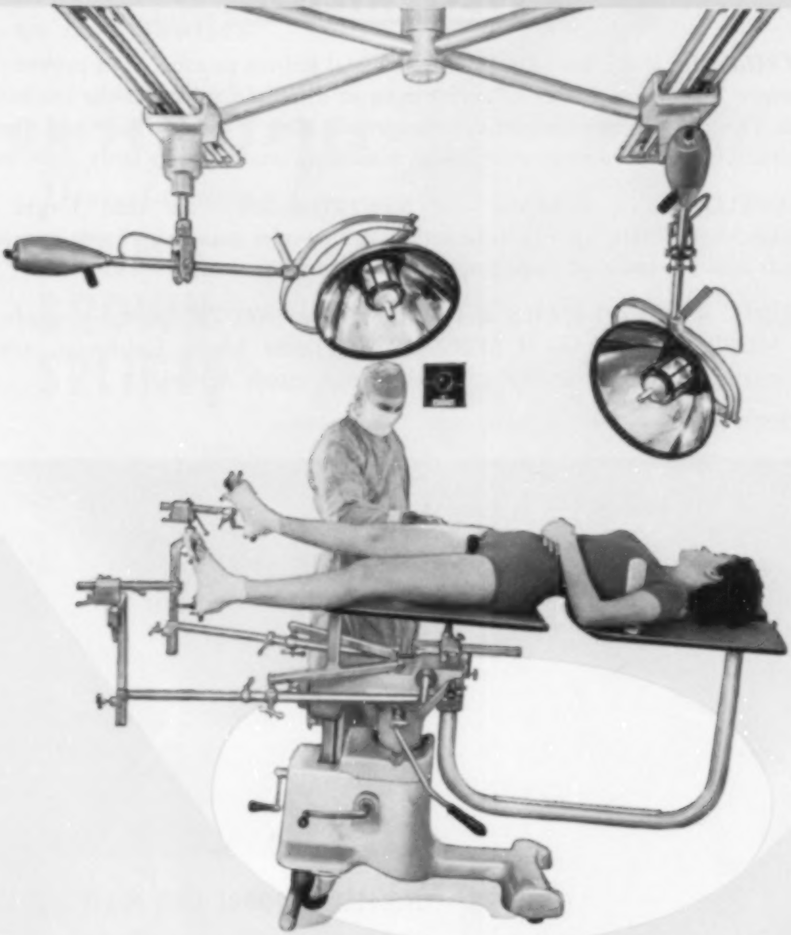
ORTHOPAEDIC *and* FRACTURE TABLE



● Acknowledged as the most versatile in its field, the American-Albee Orthopaedic and Fracture Table enables the orthopaedic surgeon to achieve "perfect positioning" of short, tall, obese and even infant patients . . . easily and rapidly. It is designed to accommodate closed fracture reductions as well as the increasing demands of complex orthopaedic surgery. Thus, to orthopaedists the world over, the name American-Albee identifies the table of choice for this comprehensive branch of medicine.

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*—IN* **NEUTRILIUM®**

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Used for internal fixation of intertrochanteric and subtrochanteric fractures.

Write for descriptive literature.

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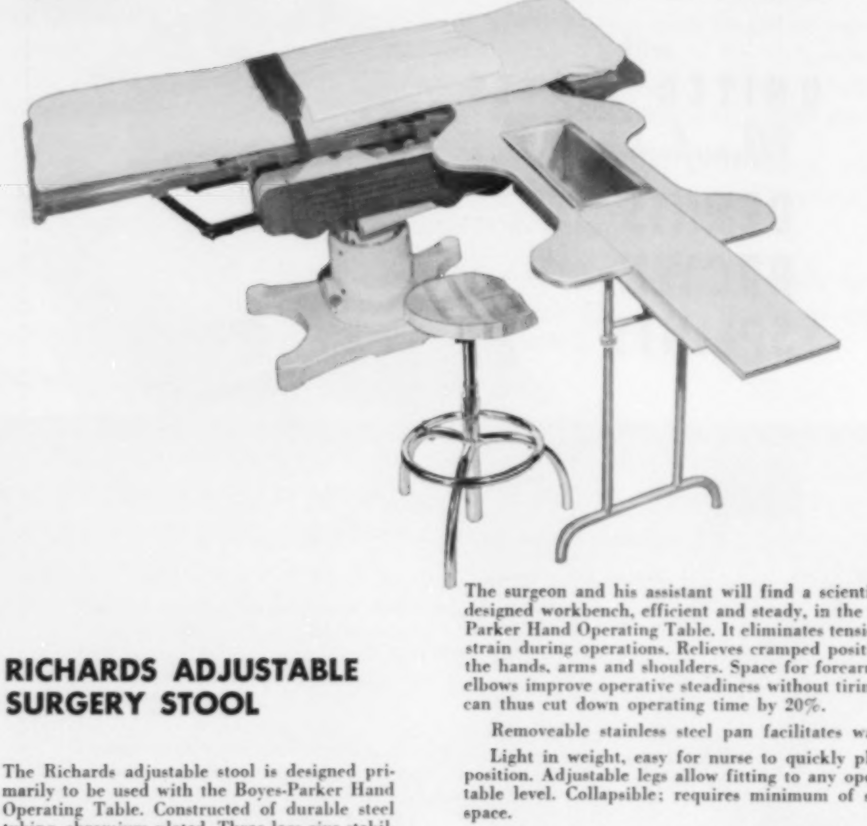
Richards

## BOYES-PARKER HAND OPERATING TABLE

(U. S. PATENT NO. 2,609,261)



The surgeon and his assistant will find a scientifically designed workbench, efficient and steady, in the Boyes-Parker Hand Operating Table. It eliminates tension and strain during operations. Relieves cramped positions of the hands, arms and shoulders. Space for forearms and elbows improve operative steadiness without tiring, and can thus cut down operating time by 20%.

Removeable stainless steel pan facilitates washing.

Light in weight, easy for nurse to quickly place in position. Adjustable legs allow fitting to any operating table level. Collapsible; requires minimum of storage space.

Pull-out instrument board places instruments in ready position for use.

Formica top; all stainless steel parts; conductive rubber ends on feet.

| | | |
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| **No. 454** | **BOYES-PARKER HAND OPERATING TABLE (Complete with No. 454A Pan)** | **$160.00** |
| **No. 454A** | **STAINLESS PAN ONLY** | **16.00** |
| **No. 454B** | **STAINLESS STEEL PAN WITH 1/4" DRAIN PLUG** | **20.00** |

## RICHARDS ADJUSTABLE SURGERY STOOL

The Richards adjustable stool is designed primarily to be used with the Boyes-Parker Hand Operating Table. Constructed of durable steel tubing, chromium plated. Three legs give stability. The stool embodies the features of an ideal seat for the hand surgeon. The saddle shaped hardwood seat is firm and comfortable, with rounded edges.

The rigid stool does not swivel; there are no casters to slide. Simple and positive up and down adjustment. By sitting on a stool that does not pivot or wobble, the surgeon can maintain an efficient, tireless posture, resting the elbows on the projecting curves of the hand table.

| | | |
|---|---|---|
| **No. 455** | **SURGERY STOOL** | **$55.00** |

—Richards MANUFACTURING CO., MEMPHIS, TENN.—

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Alden-Pedic

SCIENTIFIC CONSTRUCTION
SHOES

Style No. 84

Alden-Pedic lasts and shoes are scientifically designed to fit the individual foot shape and at the same time accommodate your prescribed corrections and insertions without sacrificing any fitting qualities. Alden-Pedic shoes are basic prescription shoes. We do not manufacture a pre-corrected or commercial health shoe.

Orthopedic surgeons familiar with the Alden-Pedic program have achieved most satisfactory results in recommending our shoes.

Write us today for our new illustrated brochure of Alden-Pedic styles for men and boys and our new "Progress Report on Shoe and Last Design".

Developed through our modern research program

- Long inside counter
- Right and left ortho heels, long inside
- Heavy gauge right and left ribbed steel shank.
- New "Depth Design" accommodates prescribed corrections

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BROCKTON, MASSACHUSETTS

FOR BOOKLET
AND NAME OF
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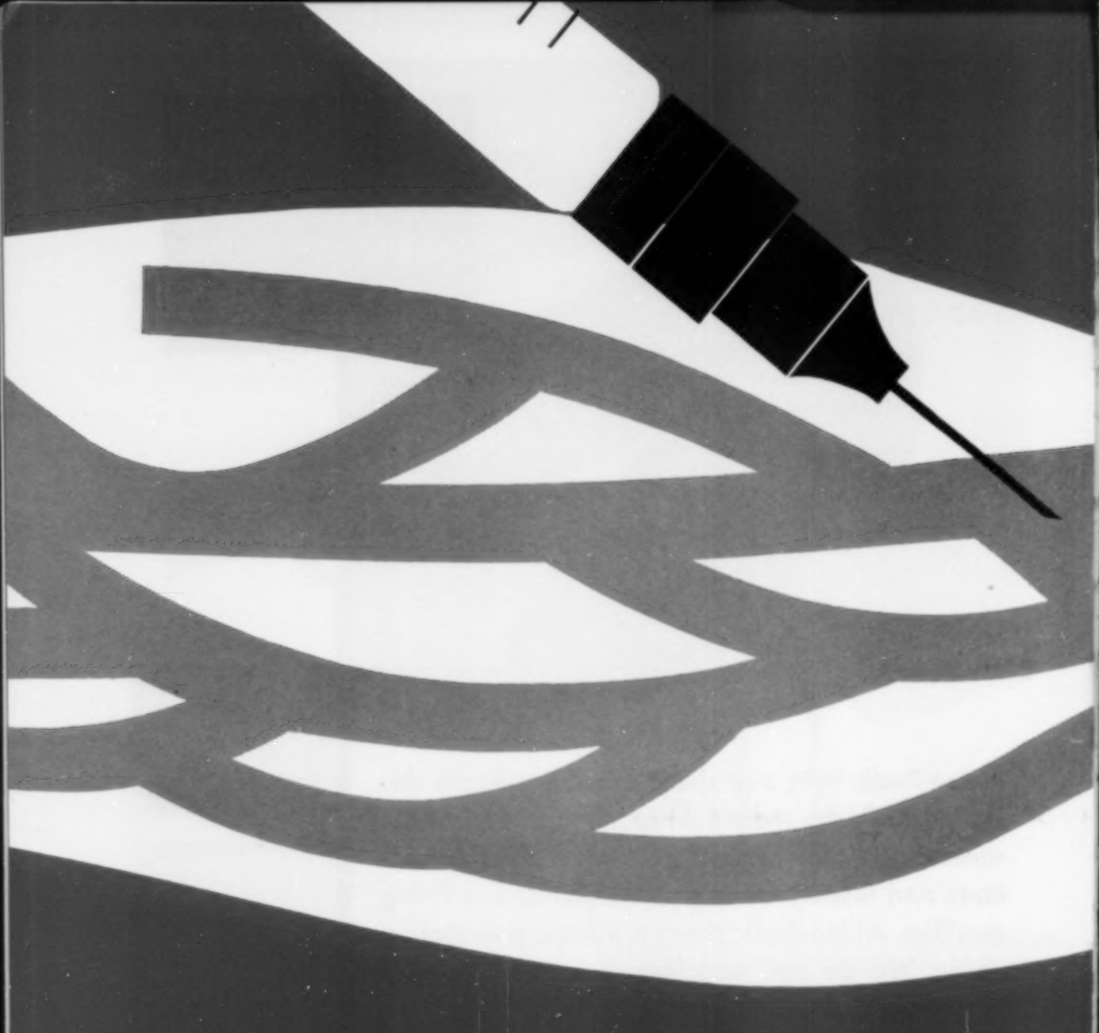

**whenever rapid corticosteroid action is imperative**

- exceptionally prompt anti-inflammatory, antistress action… effectiveness demonstrable usually within one hour
- 3 to 5 times the milligram potency of hydrocortisone
- virtually no sodium retention, edema, potassium loss

For specific information regarding indications, dosage, side effects, precautions and contraindications refer to Schering literature.

*Supply* METICORTELONE Soluble Sterile Powder,
prednisolone sodium hemisuccinate 50 mg./5 cc.; 5 cc. vial.

Meti – T.M. – brand of corticosteroids.

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prednisolone sodium hemisuccinate

**SOLUBLE**

**for accelerated, accentuated "Meti"steroid effect in adrenocortical failure**

associated with emergency or elective surgery or fulminating infections

shock unresponsive to standard therapy
life-threatening drug reactions
sight-threatening posterior-chamber eye lesions

Schering

SCHERING CORPORATION · BLOOMFIELD, NEW JERSEY

[illegible]

# a four-flanged self-cutting MEDULLARY NAIL for internal fixation of the forearm

## The Forearm

Intramedullary type internal fixation is desirable in the forearm to allow contact-compression at the fracture site and to minimize any interference with rotary motion of the radius about the ulna which occurs with metal plates.

## Surgical Technique for Fractures of the Radius

In the case of both bone fractures of the forearm, the radius is usually internally fixed first. The fracture site is exposed through a dorsal-radial incision on the radial side of the extensor tendons. The medullary nail cannot be started retrograde as in the femur and ulna; it must be driven from the distal end of the radius proximally across the fracture site. This is somewhat difficult to do, and the details of technique should be closely followed. Another short longitudinal incision is made in the "snuff box" over the radial styloid. The thumb extensor tendons are retracted and the periosteum is incised over the radial styloid. A 7/64th inch drill hole is made from the tip of the radial styloid proximally into the medullary canal. This tract should be very carefully made because if a false oblique passage is made across through the other cortex, it is very difficult to change the direction. The 3 mm nail is bent to a mild curve on one end and introduced into the hole at the tip of the styloid process. The wrist is ulnar deviated, and the nail is driven proximally into the distal fragment medullary canal to the fracture site. The fracture is reduced and the nail driven proximally over the fracture site into the medullary canal of the proximal fragment.

by
Howard W. Schneider, M.D.
Harvey, Illinois

## Surgical Technique for Fractures of the Ulna

A short, longitudinal incision is made over the subcutaneous surface of the ulna, and the fracture site exposed. The proximal fragment is lifted out into the wound with a bone hook or clamp. A long 7/64th inch drill is passed proximally into the medullary canal. A snug nail is then driven proximally up the medullary canal out through the olecranon, and a small skin incision made as the nail comes through. The nail is driven proximally until it passes the fracture site, and then the fracture is reduced. The fragments are held reduced with a bone clamp, and the nail is driven distally, and the fragments impacted. The most common sized nails are 4 to 5 mm and 18 to 26 cm long.

## Schneider Self-Cutting Medullary Nails Advantages

★ Flanges prevent rotation of fragments.

★ Maximum strength for weight of nail.

★ Cuts its own way . . . less chance of splitting the shaft. (Nail does not get stuck.)

★ Larger sized nail can be used for a snug fit. (No problem of the narrow isthmus.)

★ May be driven or extracted from either end

★ No chance of getting out of the groove. (As with separate broaches and nails.)

★ Grooves allow for free outflow of marrow fat.

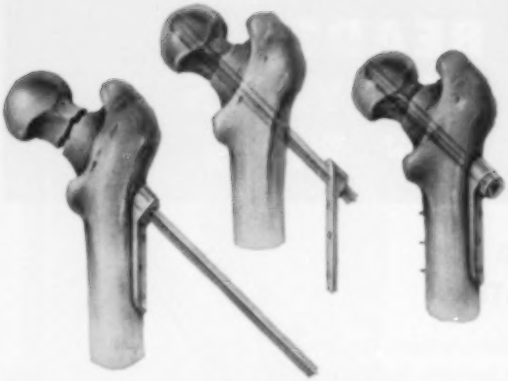
SIZES: 3, 4, 5 & 6 mm diameters . . . ulna and radius.

zimmer®

LOOK FOR THE TRADEMARK

**MANUFACTURING CO., WARSAW, INDIANA, U.S.A.**

In Japan Robert Reid, Inc. No. 1, 2-Chome Hongo Bunkyo-KU Tokyo, Japan



# BADGLEY CONTACT BLADE PLATE

*for Fractures of the Hip*

INTRACAPSULAR
EXTRACAPSULAR
INTERTROCHANTERIC
and SUBTROCHANTERIC

THREE PRIMARY FUNDAMENTAL PRINCIPLES:

1. TRIFLANGED BLADE FIXATION. STANDARD 6" LENGTH ASSURES ACCURATE NAIL LENGTH AS EXCESS LENGTH IS PRUNED.
2. CORTICAL FIXATION BY LATERAL PLATE ASSURES STABILITY OF THE BLADE.
3. FREE SLIDING OF BLADE IN CONTACT PLATE PRODUCES CONTINUOUS CONTACT AT FRACTURE SITE BY EXTRUSION OF THE BLADE OUTWARD. THE TRIFLANGED FEMALE COMPONENT OF THE CONTACT PLATE FOR THE BLADE PREVENTS ROTATION.

TECHNIQUE

INSERTION FOLLOWS TECHNIQUE OF THE SMITH-PETERSON NAIL. GUIDE WIRE MAY BE EMPLOYED IF DESIRED.

ESSENTIAL --- APPLY PLATE AND BLADE ASSEMBLED TO THE FEMUR TO MARK THE THREE FLANGES ON THE CORTEX OF THE FEMUR FOR PROPER INTRODUCTION OF BLADE SO PLATE WILL LIE IN PROPER RELATIONSHIP TO FEMORAL SHAFT. THE CORTICAL MARKINGS OF THE BLADE ARE THEN DEEPENED BY SMALL DRILL AND OSTEOTOME, OR DRILL 1/2" OPENING THROUGH OUTER CORTEX. THE NAIL MUST BE INSERTED SO THAT THE PLATE WILL LIE IN PROPER RELATIONSHIP TO THE SHAFT OF THE FEMUR. DISPLACE PLATE THEN UP THE BLADE, OUT OF THE WAY, BUT DO NOT REMOVE IT. DRIVE BLADE INTO HEAD AIDED BY ROENTGENOGRAMS. THE SIX INCH BLADE IS LONG ENOUGH TO ALWAYS ALLOW PERFECT LENGTH FOR NAIL FIXATION. THE UNNECESSARY LENGTH OF THE BLADE IS CUT OFF BY THE SPECIAL CUTTER.

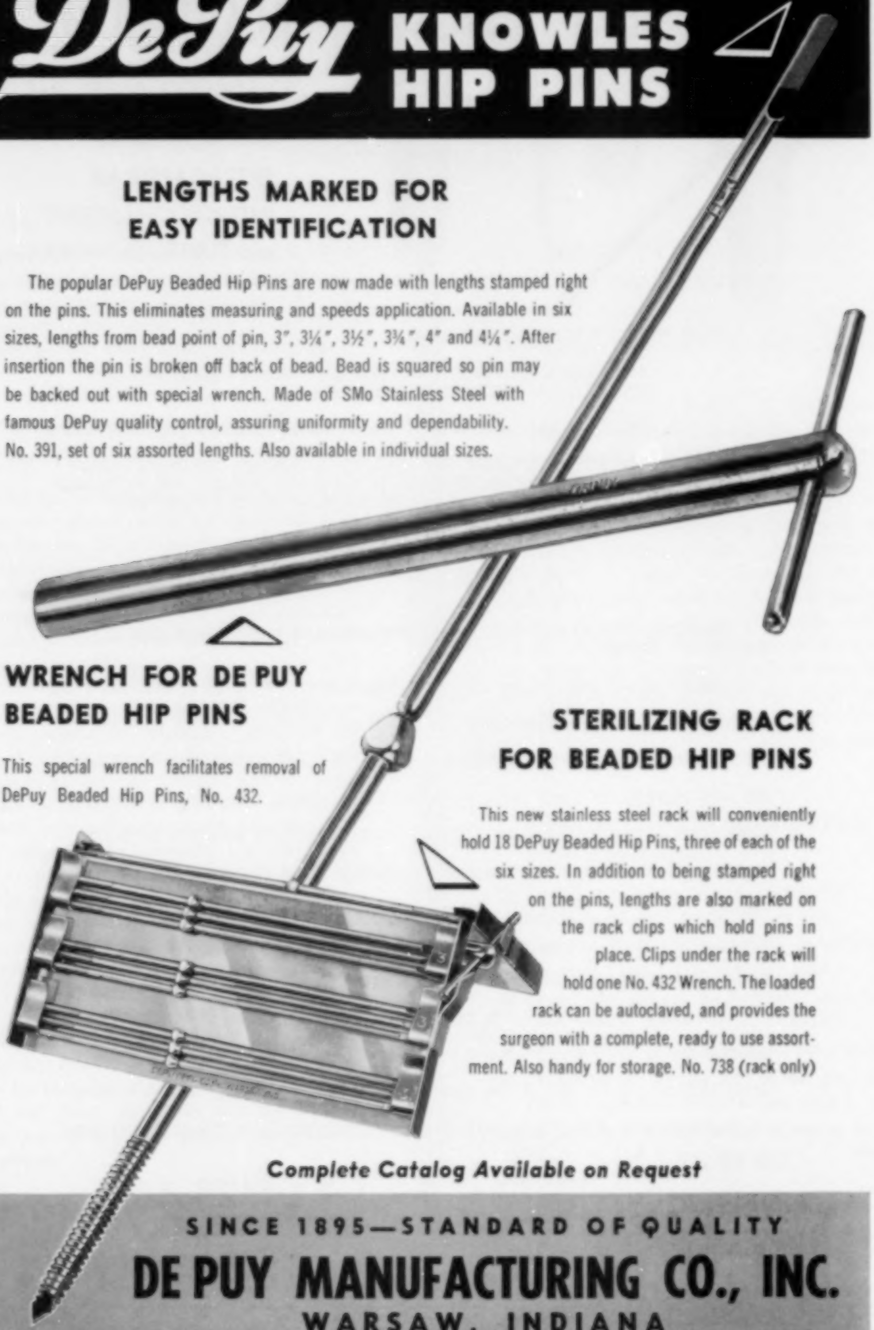
THE PLATE IS SECURED TO THE SHAFT AFTER ACCURATE NAILING IS SUBSTANTIATED BY ROENTGENOGRAMS AND THE OVER-LENGTH OF THE BLADE HAS BEEN CUT OFF. THE COLLAR ATTACHMENT TO THE CUT END OF THE BLADE IS APPLIED. THIS SERVES A DUAL PURPOSE: (A) PREVENTION OF SOFT TISSUE IRRITATION. (B) PREVENTION OF INWARD DISPLACEMENT OF THE BLADE.

Carl E. Badgley
CARL E. BADGLEY, M.D.

**zimmer**® **MANUFACTURING CO., WARSAW, INDIANA, U.S.A.**

LOOK FOR THE TRADEMARK Ⓩ

In France H Rua and Company 146 Av. Des. Champs-Elysees, Paris VIII, France



**DePuy** BEADED KNOWLES HIP PINS

LENGTHS MARKED FOR EASY IDENTIFICATION

The popular DePuy Beaded Hip Pins are now made with lengths stamped right on the pins. This eliminates measuring and speeds application. Available in six sizes, lengths from bead point of pin, 3", 3¼", 3½", 3¾", 4" and 4¼". After insertion the pin is broken off back of bead. Bead is squared so pin may be backed out with special wrench. Made of SMo Stainless Steel with famous DePuy quality control, assuring uniformity and dependability. No. 391, set of six assorted lengths. Also available in individual sizes.

WRENCH FOR DE PUY BEADED HIP PINS

This special wrench facilitates removal of DePuy Beaded Hip Pins, No. 432.

STERILIZING RACK FOR BEADED HIP PINS

This new stainless steel rack will conveniently hold 18 DePuy Beaded Hip Pins, three of each of the six sizes. In addition to being stamped right on the pins, lengths are also marked on the rack clips which hold pins in place. Clips under the rack will hold one No. 432 Wrench. The loaded rack can be autoclaved, and provides the surgeon with a complete, ready to use assortment. Also handy for storage. No. 738 (rack only)

*Complete Catalog Available on Request*

SINCE 1895—STANDARD OF QUALITY

DE PUY MANUFACTURING CO., INC.

WARSAW, INDIANA

# ...THEY CAN WALK AGAIN

Torpedoed on the Murmansk run—nearly frozen to death in an open boat—both legs lost below the knee—ex-Merchant Marines Michael McCormick and William Morris walked unaided in three weeks. They could look forward with certainty to leading a normal life again. To these men, as to thousands of other Hanger wearers, the phrase "Hanger is a symbol of help and hope" is a concrete truth proven by every day of their future lives.

**Hanger**
PROSTHESES

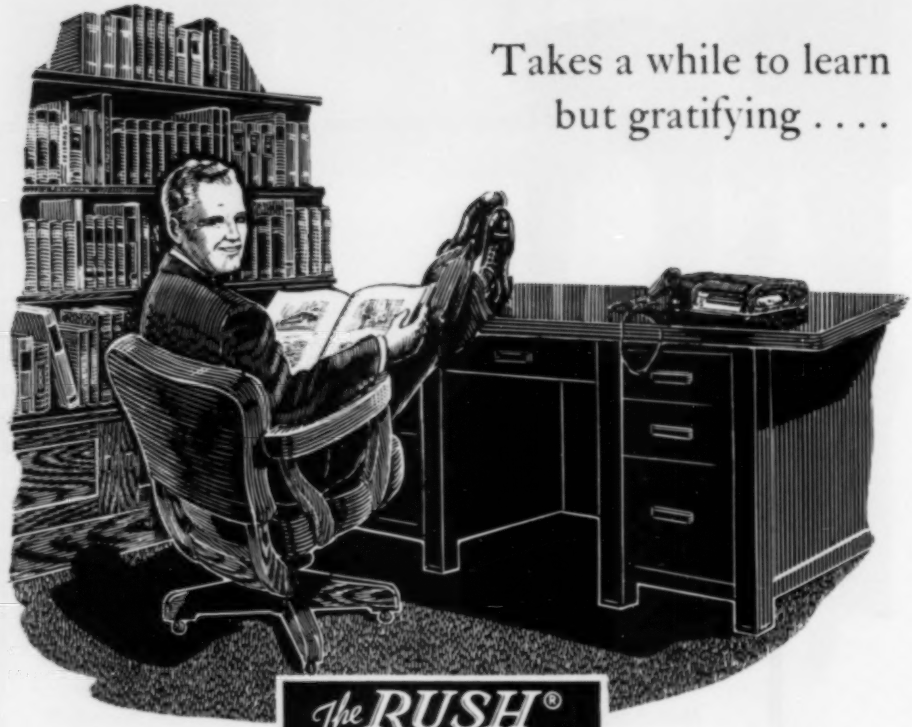
AVAILABLE AT AUTHORIZED FACILITIES IN THE FOLLOWING CITIES:

***Eastern Region:***
Baltimore 1, Md.
Boston 15, Mass.
Charleston 2, W. Va.
Charlotte 4, N. C.
New York 11, N. Y.
Philadelphia 7, Pa.
Raleigh, N. C.
Richmond 19, Va.
Roanoke 12, Va.
Washington 13, D. C.
Wilkes-Barre, Pa.

***Midwestern Region:***
Chicago 5, Ill.
Cincinnati 29, Ohio
Dallas 1, Texas
Evansville, Ind.
Fort Wayne, Ind.
Indianapolis 2, Ind.
Oklahoma City 3, Okla.
Peoria 4, Ill.
St. Louis 3, Mo.
Wichita, Kansas

***Central Region:***
Columbus 8, Ohio
Pittsburgh 1, Pa.

***Southeastern Region:***
Atlanta 1, Ga.
Birmingham 1, Ala.
Columbia 5, S. C.
Jacksonville, Fla.
Knoxville, Tenn.
Miami 37, Fla.
Mobile, Ala.
Montgomery, Ala.
Nashville, Tenn.
New Orleans 19, La.
Orlando, Fla.
Shreveport, La.
Tampa 2, Fla.
West Palm Beach, Fla.



Takes a while to learn
but gratifying . . . .

*The* **RUSH**®
**MEDULLARY PIN**
Pat. No. 2,579,968

Proper application of the RUSH PIN is not always easy. It takes a while to learn. It is quite different in principle and technic from other forms of medullary fixation. It is not designed to impact the marrow cavity, but to accurately transfix the fractured bone by points of pressure, precisely applied.

The ingenious surgeon, who has added this to his knowledge and skills, has simplified his tasks and contributed pleasure to his patients. He minimizes surgery and speeds convalescence with unbelievably early motion, even in fractures near joints. Removable splints are sometimes used, but casts or traction, rarely.

The patient is more comfortable, the hospital stay is shortened. And best of all, the recovery time and residual disability can be markedly lessened.

It does take a while to learn, but it IS GRATIFYING!

*Write for Information*

**THE BERIVON**
*Company*
**MERIDIAN, MISS.**

EXCLUSIVE MANUFACTURERS OF **RUSH** MEDULLARY PINS AND INSTRUMENTS
Publishers of **"ATLAS OF RUSH PIN TECHNICS"** by LESLIE V. RUSH, M. D.

# How well do you know the other brand of elastic bandage?

***Doctors prescribe over half of the elastic bandages used - - - yet they often mistake a brand name for the bandage itself!***

Think back a moment, doctor. How often in prescribing an elastic bandage have you used a brand name unintentionally when you just meant any elastic bandage?

Of course you didn't mean to. You know there are two important brands of elastic bandages . . . each a fine product in its own right.

But how well do you really know (and remember) the *other* brand . . . the TENSOR elastic bandage? Tests prove it's the very one you ought to remember.

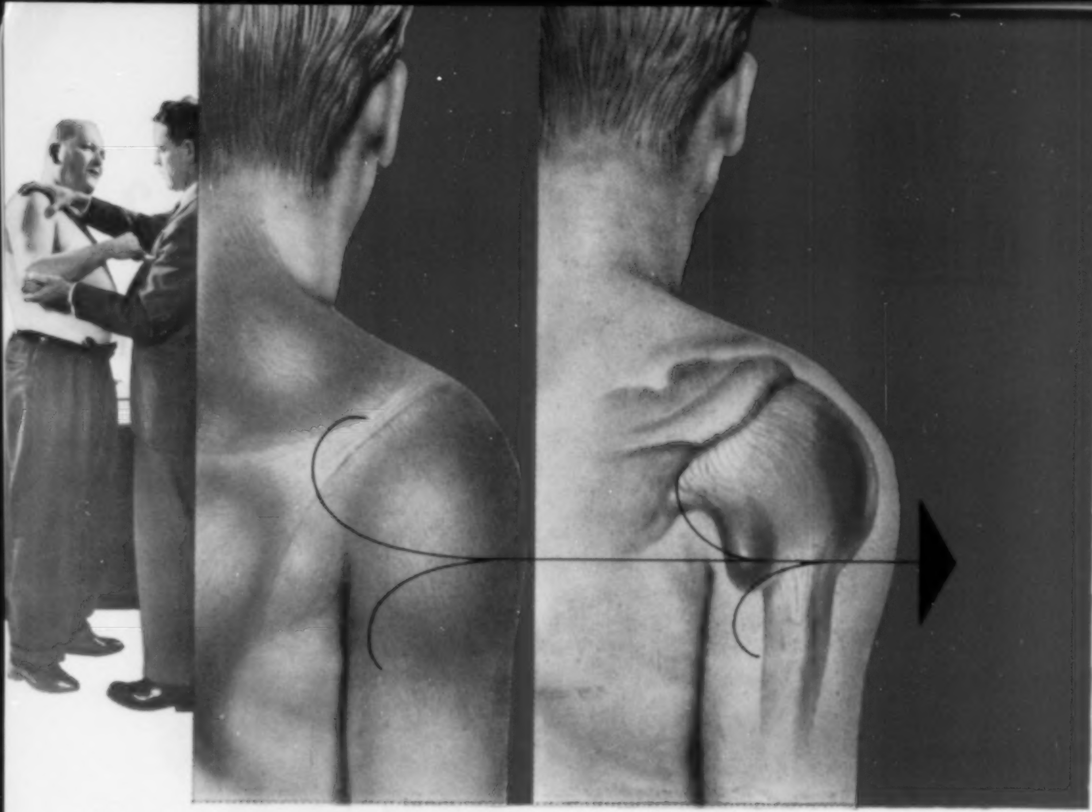
**FOR THESE REASONS:**

1. **TENSOR** is made with live rubber threads that don't die in the laundry, but are specially heat-resistant to keep positive stretch and snap-back despite laundry dryer heat.
2. **TENSOR** has long-stretch action which enables it to offer proper compression throughout a greater stretching area.
3. **TENSOR** is self-conforming . . . adjusts itself to the swelling. For instance, if you wrap the bandage, doctor, the pressure you apply is the pressure TENSOR maintains.
4. **TENSOR** has thin plastic tips that eliminate bulky pressure points . . . make it easy and safe to apply.

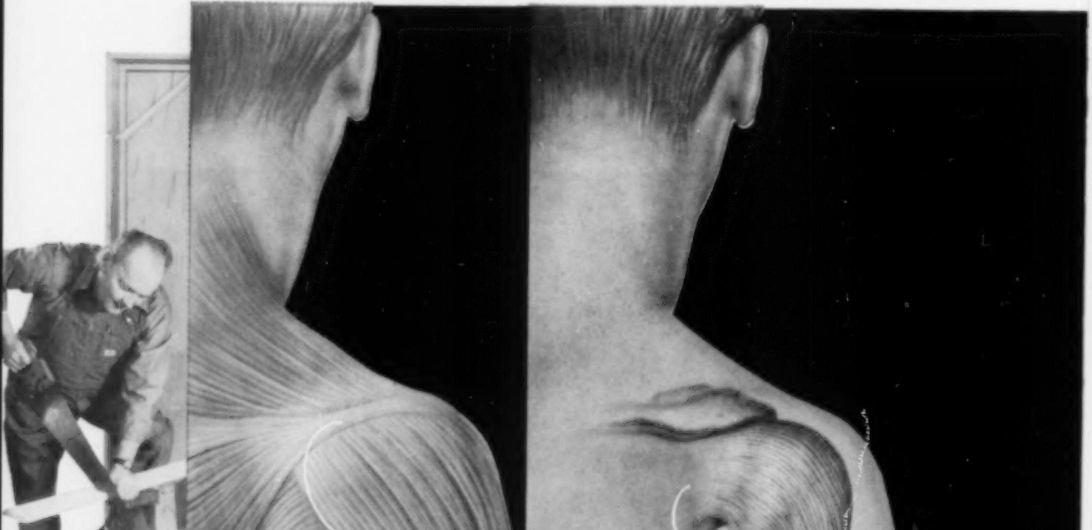
Only one bandage offers patients all these benefits. The name, again, is TENSOR.

**TENSOR®**
**ELASTIC BANDAGE**
WOVEN WITH HEAT-RESISTANT LIVE RUBBER THREADS
**Bauer & Black**
DIVISION OF THE KENDALL COMPANY

3"
5½ YARDS STRETCHED
LIVE RUBBER
Curity
TENSOR®
Elastic
BANDAGE
BAUER & BLACK



"Rheumatoid arthritis is a constitutional disease with symptoms affecting chiefly joints and muscles."[1] "Pain in the affected joint is accompanied by splinting of the adjacent muscles, with resultant 'muscle spasm.'"[2]



**rheumatoid arthritis**

**involves both**

**joints and**

**muscles**

MEPROLONE is the only anti-rheumatic-antiarthritic designed to relieve simultaneously (a) muscle spasm (b) joint-muscle inflammation (c) physical distress . . . and may thereby help prevent deformity and disability in more arthritic patients to a greater degree than ever before.

SUPPLIED: Multiple Compressed Tablets in two formulas: MEPROLONE-2—2.0 mg. prednisolone, 200 mg. meprobamate and 200 mg. dried aluminum hydroxide gel (bottles of 100). MEPROLONE-1—supplies 1.0 mg. prednisolone in the same formula as MEPROLONE-2 (bottles of 100).

1. Comroe's Arthritis: Hollander, J. L., p. 149 (Fifth Edition, Lea & Febiger, Philadelphia, Pa. 1953).
2. Merck Manual: Lyght, C. E., p. 1102 (Ninth Edition, Merck & Co., Inc., Rahway, N. J. 1956).

**only**

# MEPROLONE®

THE FIRST MEPROBAMATE PREDNISOLONE THERAPY

meprobamate to relieve muscle spasm
prednisolone to suppress inflammation

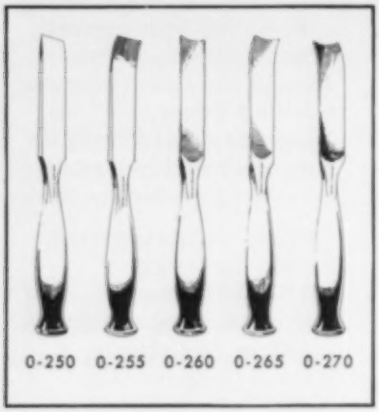
**relieves both**

**muscle spasm**

**and joint inflammation**

MSD MERCK SHARP & DOHME Philadelphia 1, Pa.
Division of MERCK & CO., INC.

# SMITH-PETERSEN OSTEOTOMES and GOUGES



**0-250** SMITH-PETERSEN OSTEOTOME—straight, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

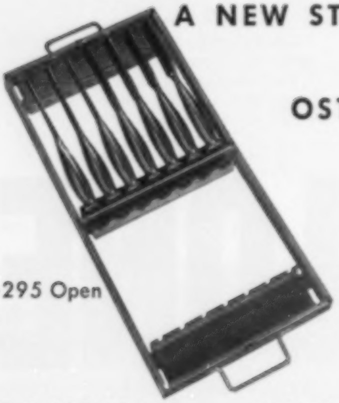
**0-255** SMITH-PETERSEN OSTEOTOME—curved, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

**0-260** SMITH-PETERSEN GOUGE—straight, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

**0-265** SMITH-PETERSEN GOUGE—curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

**0-270** SMITH-PETERSEN GOUGE—reverse curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

## A NEW STAINLESS STEEL CASE TO HOLD SMITH-PETERSEN OSTEOTOMES and GOUGES



0-295 Open

**CASE 0-295**—holds seven Smith-Petersen Osteotomes.

**CASE 0-296**—holds seven Smith-Petersen Gouges.

**CASE 0-297**—holds a combination of seven Osteotomes and Gouges.

**Cutting edges are protected at all times. Complete unit may be autoclaved.**

0-295 Closed

*Specify Width of Gouges and Osteotomes When Ordering*

CS
ESTABLISHED 1838

**Codman & Shurtleff, Inc.**

MAKERS OF SURGEONS' INSTRUMENTS

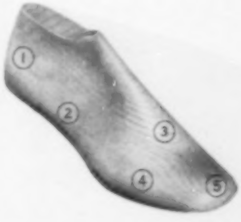
104 BROOKLINE AVENUE BOSTON 15, MASSACHUSETTS

**Child Life**
**SHOES**

## Correct in last

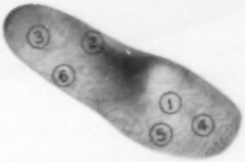
From the point of view of orthopedic men, no shoe can be better than the last over which it is made. For this reason, CHILD LIFE lasts are visualized for you here, so that you can literally see for yourself why these juvenile shoes merit your professional interest. You will be glad to know, too, that CHILD LIFE dealers have been selected for the time they will take to *really fit* the shoe to the child's foot. Names of dealers in your area will be gladly sent to you at your request.

### Regular Last



1 Bulb-shaped heel fits perfectly, snugly, without biting or irritation.
2 Ample displacement for the "cuboid roll."
3 Ample height at the large toe joint area for freedom in flexing.
4 Generous height at the small toe area to prevent irritation to the fifth toe.
5 Ample width and height over the toes give room enough for maximum growth.

### Arch Feature Last

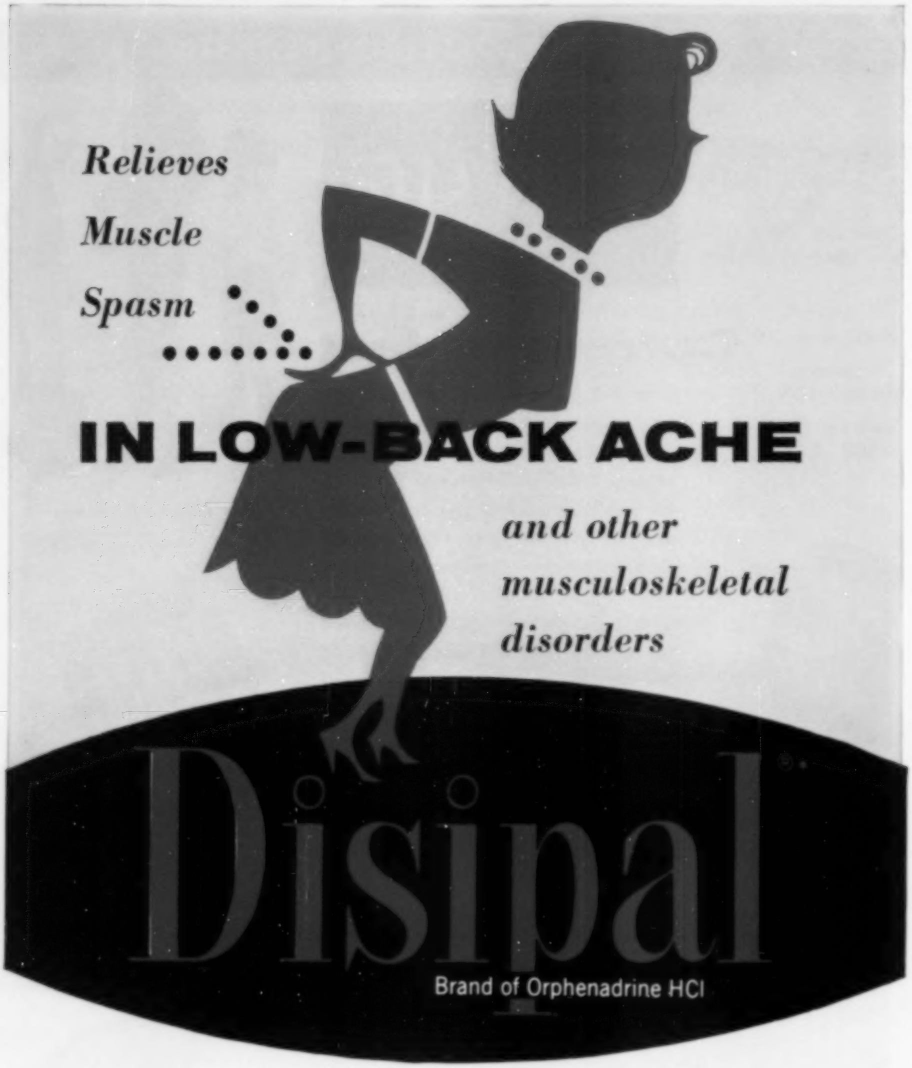


1 Slight contouring for the forefoot.
2 Medial wedge removed from last for added support.
3 Heel two widths narrower for snug fit.
4 Ample width and height over the toes give room enough for maximum growth.
5 Generous height at the small toe area to prevent irritation to the fifth toe.
6 Ample displacement for the "cuboid roll."

**Child Life**
**SHOES**

## Herbst Shoe Manufacturing Company

MILWAUKEE 45, WISCONSIN


Relieves
Muscle
Spasm
IN LOW-BACK ACHE
and other
musculoskeletal
disorders
Disipal*
Brand of Orphenadrine HCl

## Relieves Spasm, Pain, and Depression too

In muscle spasm due to sprains, strains, herniated intervertebral disc, fibrositis, noninflammatory arthritic states and many other musculoskeletal disorders, the first demand is for relief. Disipal fills this need. It is quickly effective in skeletal muscle spasm almost regardless of origin. Its mood-alleviating effect braces the patient against the depression so often accompanying severe pain of any type.

Dosage: 1 tablet (50 mg.) t.i.d.

**In Parkinsonism**

Highly selective action...energizing against weakness, fatigue, adynamia and akinesia...potent against sialorrhea, diaphoresis, oculogyria and blepharospasm...lessens rigidity and tremor...alleviates depression...safe...even in glaucoma.

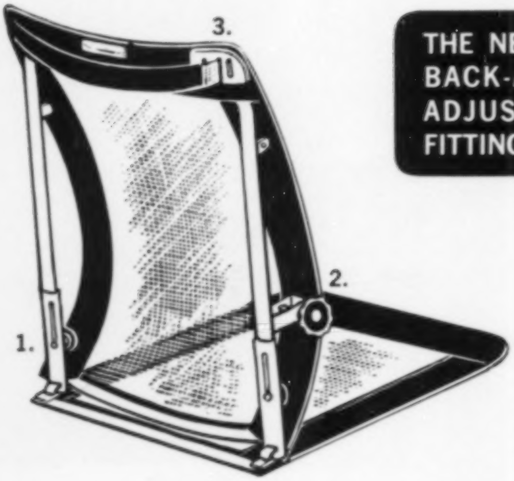
*Trademark of Brocades-Stheeman & Pharmacia.
U.S. Patent No. 2,567,351. Other patents pending.

Riker
LOS ANGELES

# FOR BACK SUFFERERS

# who drive cars

## HERE'S PROPER SPINAL SUPPORT AND FIRM UNDERSEATING



**THE NEW MARK-FORE ADJUSTABLE BACK-AIDE FEATURES 3 SIMPLE ADJUSTMENTS FOR INDIVIDUAL FITTING AND PERSONAL COMFORT.**

1. Adjusts for individual sitting height and figure type.
2. Adjusts for degree of firmness of support in low-back area.
3. Adjusts to upright position for full-view vision.

**Obesity, pregnancy, arthritis, sciatica, slipping and degeneration of discs, abdominal surgery, postural strain — for these, and similar complaints involving the musculo skeletal system, particularly of the lower back, the Mark-Fore adjustable Back-Aide was scientifically designed.**

While seats in the modern automobile are adjustable, there is not sufficient adaptability to the variations in the anatomy of people, their differences in height, body type, and variations in the relative length of their limbs and trunk. The Mark-Fore adjustable Back-Aide, however, can be quickly fitted to and by the individual, and easily readjusted to any changing needs.

**The Mark-Fore adjustable Back-Aide will soon be available in leading department stores throughout America.**

SPECIAL OFFER TO DOCTORS: Send this coupon today for a Mark-Fore adjustable Back-Aide at the professional price of $7.50 postpaid (regular retail price: $12.95), and/or descriptive literature for distribution to patients. Each Mark-Fore adjustable Back-Aide is constructed of Fiberglas mesh with a special alloy steel frame and luxurious Lum-Puf Saran and heavy vinyl leatherette.

MARK FORE
ADJUSTABLE PAT. PENDING BACK-AIDE

**ARKET FORGE COMPANY EVERETT 49, MASSACHUSETTS**

Please send me a Mark-Fore adjustable Back-Aide at the professional price of $7.50 postpaid in the following color combination:

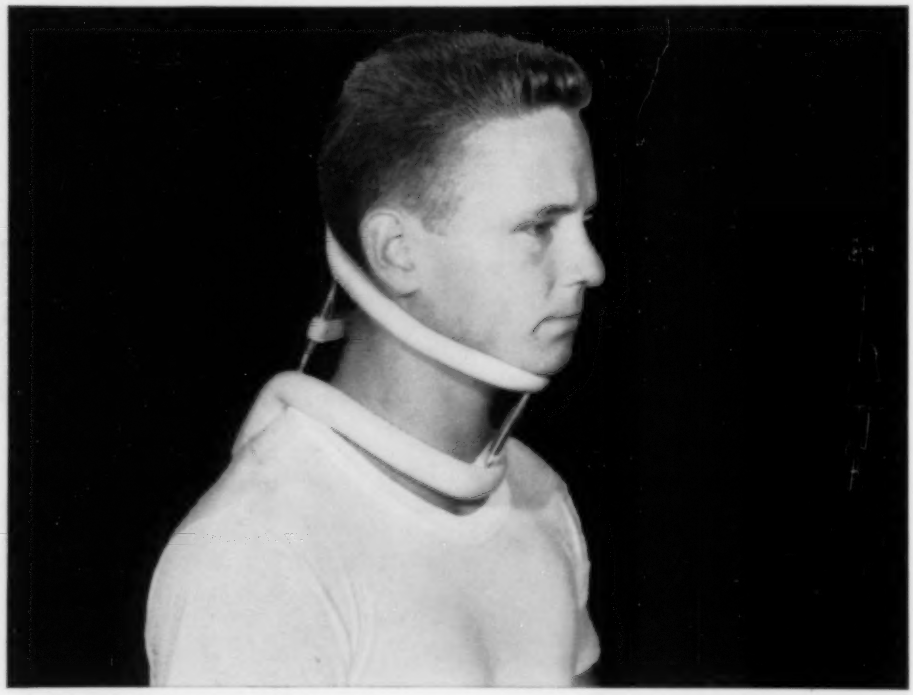
☐ Ivory & Gold. ☐ Ebony & Silver.
☐ Check Enclosed. ☐ Bill Me.
☐ Please send me descriptive literature for distribution to patients.

NAME:
STREET:
CITY: STATE:

To be sent to: Market Forge, Everett 49, Mass.

# NEW CAMP VICTORIA COLLAR

*is adjustable for both positions of extension and flexion*



When the patient needs neck support for cervical syndrome, subluxations, arthritis, cervical radiculitis . . . when convalescence after casts in fractures or dislocations is indicated, this new, universal Thomas Collar offers the most effective, comfortable support. The "open throat" area assures comfort during hot and cold seasons . . . it is light, yet the simple, rigid construction gives greater patient support than other Thomas Collars. It has the double advantage of (1) being adjustable for positions of extension and flexion (2) having a wide range of adjustability for various neck heights. Easy to put on, adjust and shape to fit. The bottom ring is supported by the patient's shoulder girdles and the adjusting turnbuckles regulate the height of the ring . . . thus the desired height and immobility is attained. Available in small, medium and large sizes.

CAMP TRADE MARK

**S. H. CAMP and COMPANY**

Jackson, Michigan

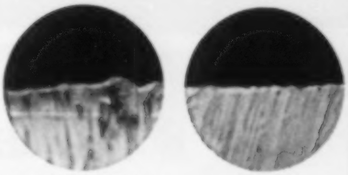
now available! SteriSharps® the first sterile, stainless-steel blade

## *NEW* SteriSharps guarantee surgeons consistent sharpness...in every blade!

SteriSharps are the sharpest, most uniform, most durable sharps made today—assure surgeons flawless blade performance *every single time!* Only SteriSharps are tested by the A·S·R Sharpometer®—an instrument that measures sharpness electronically. Guarantees consistent sharpness blade after blade—without fail.

And SteriSharps eliminate old methods of handling and preparing blades—methods that may destroy asepsis, impair the cutting edge. SteriSharps come sealed in foil, ultrasonically cleaned and ready for instant use. Free samples available to surgeons. Write: A·S·R Hospital Division, Dept. BS, 380 Madison Ave., N.Y. 17, N.Y.

### DRAMATIC PROOF OF STERISHARP SUPERIORITY

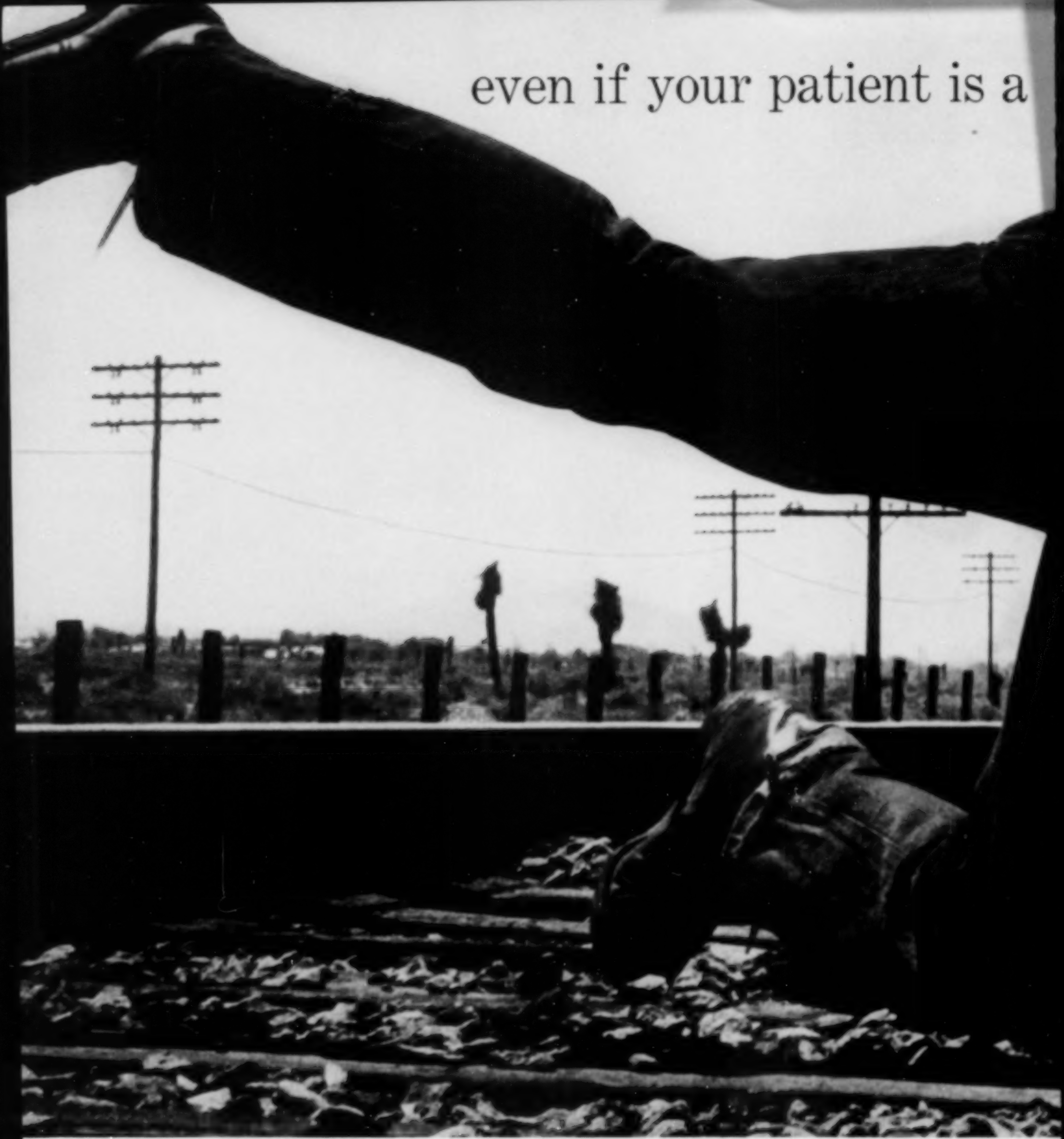


ORDINARY BLADE STERISHARP

These unretouched photos (magnified 1,000 times) show that you can sometimes get a dull carbon blade...demonstrate the superiority of new SteriSharps. The ordinary blade edge (left) is ragged . . . has nicks and burrs that can snag tissue. The SteriSharp (right) has a clean, uniform edge.

A·S·R precision products

SteriSharps... the first and only sterile, stainless-steel surgical bla


even if your patient is a

...he'll be back on the track with

Low back syndromes ... sprains ... strains ...

FLEXILON gets them back

**McNEIL** LABORATORIES, INC · PHILADELPHIA 32, PA.

108A58

# gandy dancer†

†railroad man's term for track section hand

# FLEXILON*

(FLEXIN® + TYLENOL®)

rheumatic pains...

on the job fast.

Each tablet contains:
FLEXIN® Zoxazolamine‡ . . . . 125 mg.
*The most effective oral skeletal muscle relaxant*
TYLENOL® Acetaminophen . . . 300 mg.
*The preferred analgesic for painful musculoskeletal disorders*
supplied: Tablets, enteric coated, orange, bottles of 50.

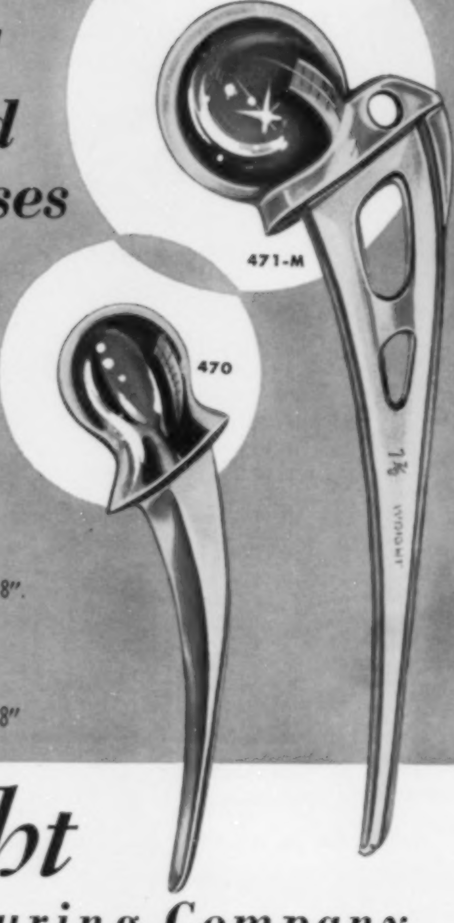
‡U.S. Patent Pending *Trade-Mark

SMo stainless steel drop forged hollow head hip prostheses

neutral position

Austin Moore & Thompson types by Wright

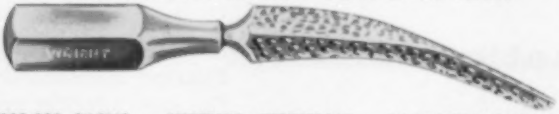
471-M Austin Moore Hip
Prosthesis Head Diameter Sizes:
1-5/8″, 1-3/4″, 1-7/8″, 2″, 2-1/16″, 2-1/8″.
470-Thompson Hip
Prosthesis Head Diameter Sizes:
1-5/8″, 1-3/4″, 1-7/8″, 2″, 2-1/16″, 2-1/8″



Wright
Manufacturing Company

Each prosthesis manufactured by Wright is precision constructed of the finest materials to rigid specifications and must pass the most exacting Zyglo inspection before being released for use. These prostheses closely approximate the anatomical configurations of the femur.

STAINLESS STEEL RASP ASSURES MAXIMUM ACCURACY IN SHAPING HARD INNER CORTICAL BONE OF MEDULLARY CAVITY OF THE FEMUR.



WRIGHT MFG. CO. • 880-882 ADAMS • MEMPHIS, TENNESSEE • TELEPHONE JAckson 5-0619

*Compazine**

**prevents postoperative nausea and vomiting**

'Compazine' can be depended upon to have little, if any, hypotensive effect.

*Available:* Ampuls, Multiple dose vials, Tablets, Spansule† capsules, Syrup and Suppositories.

*Smith Kline & French Laboratories, Philadelphia*

*T.M. Reg. U.S. Pat. Off. for prochlorperazine, S.K.F.
†T.M. Reg. U.S. Pat. Off. for sustained release capsules, S.K.F.

**renew vitality with...**

*new*
*improved formula*

**"MEDIATRIC"**

The improved "Mediatric" formula helps renew the vitality of your elderly patients and makes them more able to cope with the stress of old age. The new formula "Mediatric" provides, in addition to the steroids, 100% more Vitamin C, twice as much $B_1$, added B factors, and lower iron dosage (to lessen gastric irritation yet adequate for specific therapy).

It also contains a mild antidepressant to give a gentle, emotional lift.

*new*
*improved formula* **"MEDIATRIC"®**
steroid-nutritional compound

Each capsule or tablet contains:

| | |
|---|---|
| Conjugated estrogens equine ("Premarin"®) | 0.25 mg. |
| Methyltestosterone | 2.5 mg. |
| Vitamin C (ascorbic acid) | 100.0 mg. |
| Vitamin $B_{12}$ with intrinsic factor concentrate | 1/6 U.S.P. Unit |
| Thiamine mononitrate ($B_1$) | 10.0 mg. |
| Riboflavin ($B_2$) | 5.0 mg. |
| Nicotinamide | 50.0 mg. |
| Pyridoxine HCl ($B_6$) | 3.0 mg. |
| Calc. pantothenate | 20.0 mg. |
| Folic acid U.S.P. | 0.33 mg. |
| Ferrous sulfate exsic. | 30.0 mg. |
| *d*-Desoxyephedrine HCl | 1.0 mg. |

*Suggested Dosages:* Male – 1 capsule or 1 tablet daily, or as required. Female – 1 capsule or 1 tablet daily, or as required, taken in 21 day courses with a rest period of one week between courses.

*Supplied:* Capsules – No. 252 – Bottles of 30, 100, and 1,000. Tablets – No. 752 – Bottles of 100 and 1,000.

AYERST LABORATORIES • New York 16, New York • Montreal, Canada

5829

# ACCLAIMED BY SURGEONS AS THE LIFETIME INSTRUMENTS

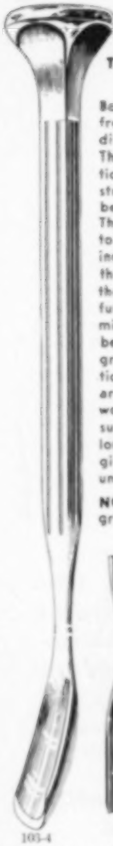
*Because of Their Quality and Durability*

## GOUGES

**Type 440C Stainless Steel—Swedish Hand Forged**

Bowen Gouges, Hand Forged from 44C stainless steel, are of distinctive design and style. The forging method of fabrication produces a fine grain instrument in curves and shapes best desired by the surgeon. The edges are hollow ground to keen razor sharpness resulting in a minimum of effort on the part of the surgeon to make them perform their intended function. The four styles permit a wide range of work to be done. They will be found of great value in bone reconstruction work. The Curved Gouges are particularly adaptable to work in and around contoured surfaces. The fine balance and long square grooved handles give a feeling of sure grip and unobstructed vision.

**NOTE:** Available with finger grips if desired.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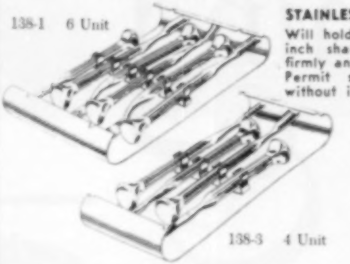
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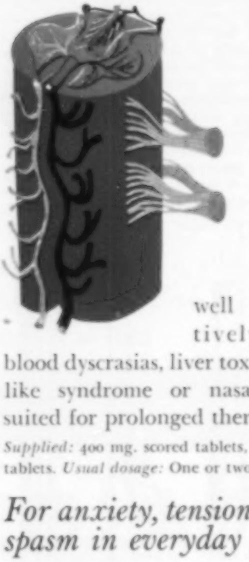

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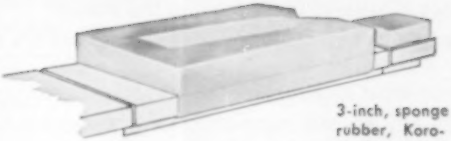

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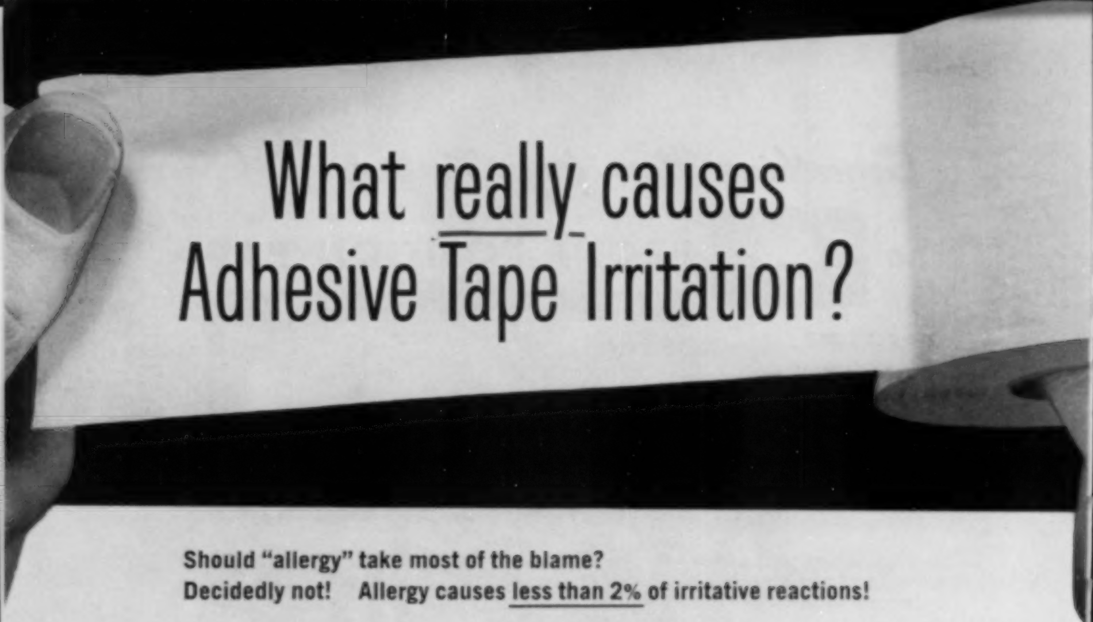

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Bone and Joint Surgery
*American Volume*

# The Chronology of Circulatory Changes in Poliomyelitis *

BY ARTHUR W. TROTT, M.D., MARY D. NESLINE, B.A.,
AND WILLIAM T. GREEN, M.D., BOSTON, MASSACHUSETTS

*From the Departments of Orthopaedic Surgery,
The Children's Hospital and Harvard Medical School, Boston*

In the North Temperate Zone, coldness and cyanosis of the lower extremities are often important secondary manifestations of severe paralysis in poliomyelitis. It has been our purpose to study the origin of the circulatory changes responsible for these findings and to observe their sequential development.

The observations of this study were made upon patients enrolled in a longitudinal study of growth of the lower extremities in which one extremity was normal and the other was paralyzed. In all, there were 153 patients who were observed at various intervals during the first three years of the disease. Measurements of the cutaneous and muscle temperatures, made periodically under controlled conditions, were used as an index of the circulatory state. By the use of both skin and muscle temperatures, the status of the peripheral circulation can be measured at two different depths and in different tissues. The fact that the patients had one normal and one paralyzed extremity allowed a direct comparison of one side with the other.

As near as could be determined on a clinical basis, these patients had no evidence of circulatory disease other than that which might be due to poliomyelitis. None of the patients were afflicted with the bulbar or spinal respiratory forms of the disease. Initial measurements of temperature were performed as soon as possible after the onset of the illness, the earliest of which were recorded at eight days. Those patients who were followed under ideal circumstances were tested weekly while hospitalized, and subsequent examinations were performed every three months during the first year of the illness, and every six months after this interval. Although much of the data were longitudinal in nature and represented serial examinations performed upon individual patients over a period of time, this material was augmented by observations on patients who had single examinations or examinations at irregular intervals. The tests performed ranged from one to twenty-five per patient with an average of five. The series was composed mostly of children, although there were a few adults. The average age of the group was 6.5 years, the range being ten months to twenty-nine years. Ninety-seven per cent of the group were within the ranges of one to fourteen years.

The patients in this study were divided into three groups based upon the degree of residual paralysis below the knee, as this constituted the region where most measurements were made. Each muscle in the leg was assigned a numerical rating which was

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* Aided by a grant from The National Foundation for Infantile Paralysis.

weighted according to function and power. The value on this scale if all muscles were normal was 40. The group designated as *good*, the upper third, was rated 26.6 to 39.9, the group designated *fair*, the middle third, was rated 12.6 to 26.5, and the group designated *poor*, the lower third, was rated 0 to 12.5. The latter group had little or no effective power in the leg. It is recognized that this is an arbitrary grouping, but it agrees closely with clinical judgment as to the severity of paralysis.

The relative temperature of the skin and muscle is a reliable index of the vascular flow when certain specifications are met [9]. This method has long been used for clinical comparisons and under the circumstances of this investigation it was more easily adapted to the study of the peripheral circulation of these patients with poliomyelitis than were other methods such as plethysmography and oscillometry. Comparative determinations by means of radioactive isotopes have not been made in this series nor can the relative value of these methods and the one used in this study be assessed at this time. The measurement of temperature of the skin and muscle has the particular advantage that the test can be performed in the earlier stages of the disease without disturbing to any significant degree the local environment of the extremity.

## METHOD

Qualitative measurements of blood flow were performed by determinations of skin and muscle temperature. To record the temperature of the skin (in degrees of Fahrenheit) iron-constantan thermocouples connected to a potentiometer were used. Identical areas of skin were measured on both lower extremities and these included: (1) pulp of the great toe, (2) dorsum of the foot, (3) medial malleolus, (4) shin at the point of maximum circumference of the calf, (5) tibial tuberosity, (6) medial femoral condyle, and (7) skin over the medial mass of the gastrocnemius muscle. These areas were selected because they allowed sampling of skin temperatures in close proximity to epiphyses where growth is maximal and because they offered a wide distribution of sites for measurement.

Muscle temperatures were measured by the same apparatus with 34-gauge iron and 35-gauge constantan wire joined at the tip of 20- to 23-gauge hypodermic needles. The needles were inserted into the medial mass of the gastrocnemius muscle for three-fourths to one and one-half inches depending upon the size of the patient.

The measurements of the skin and muscle temperatures were performed under specified conditions as follows:

1. Most tests were done in a room which was maintained at as nearly a constant level as possible by means of an air conditioner, within the range of ± 2.0 degrees Fahrenheit, and ordinarily with an essentially fixed temperature.
2. Tests were performed at various room temperatures ranging from 57.6 degrees to 81.5 degrees Fahrenheit. Originally this variability arose in testing patients during the acute stage of the disease who could not be moved into a room with controlled temperature. In some instances *, a high or low room temperature was used for a particular purpose.
3. The patient lay recumbent with the lower extremities exposed to room air for at least twenty minutes to allow adjustment to the controlled room temperatures.
4. Records of the temperature of the skin were made at each of the previously mentioned areas in the order listed.
5. Readings of temperatures were taken at ten-minute intervals until equilibrium was attained.

The data obtained were analyzed by several methods. The mean differences in temperature of the skin and muscle between corresponding areas of the paralyzed limb and its opposite normal limb were compared. In addition, the individual differences of cutaneous temperatures at each level were combined and recorded as an average aggregate difference. This was felt to be a more valid method for this study than the weighted formula of Hardy and DuBois which assigned an exaggerated importance to the area about the medial femoral condyle. In order to substantiate the significance of the differences in temperatures found between the paralyzed and unparalyzed extremities, comparisons were made of the findings in the poliomyelitic patients with the findings in a group of normal persons, both in regard to the relative temperatures at the different areas of skin on each extremity and to the average aggregate differences.

In the instance of the skin temperature, the normal series was composed of ninety-eight persons and 1,491 observations, which is more than an adequate group for direct comparison. Muscle temperatures in

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* In order to make use of the variable room temperatures, similar tests were performed under identical conditions upon normal individuals. It was found that the variability in room temperature was of less importance than in the usual determinations of cutaneous temperature since the opposite normal limb acted as a control.

TABLE I

Effect of Time and Residual Muscle Power
upon Relative Skin Temperatures Following Poliomyelitis

Average Aggregate Differences and Standard Deviations (in Degrees Fahrenheit)
between Normal and Involved Extremities in 153 Patients with Unilateral Paralysis

| Time after Onset | Residual Muscle Power | | | | | | No. of Tests (Including All Areas) |
|---|---|---|---|---|---|---|---|
| | Good | | Fair | | Poor | | |
| | Mean | σ | Mean | σ | Mean | σ | |
| First year | | | | | | | |
| 1– 20 days | −0.36 | ±1.04 | +0.03 | ±0.95 | +0.26 | ±1.62 | 214 |
| 21– 40 days | −0.01 | ±0.95 | −0.05 | ±1.42 | −0.38 | ±2.21 | 304 |
| 41–120 days | −0.24 | ±1.28 | −0.50 | ±1.54 | −0.61 | ±2.26 | 599 |
| 5– 6 months | −0.52 | ±1.14 | −0.96 | ±1.94 | −1.42 | ±1.72 | 386 |
| 7– 9 months | −1.21 | ±1.63 | −1.67 | ±1.85 | −2.28 | ±1.81 | 526 |
| 10–12 months | −0.90 | ±1.00 | −1.32 | ±1.51 | −2.26 | ±2.01 | 411 |
| Second year | | | | | | | |
| 13–18 months | −1.15 | ±1.48 | −2.01 | ±1.86 | −3.36 | ±2.65 | 839 |
| 19–24 months | −0.80 | ±1.52 | −1.27 | ±1.90 | −2.31 | ±2.37 | 538 |
| Third year | | | | | | | |
| 25–30 months | −0.69 | ±1.76 | −1.84 | ±2.34 | −3.11 | ±2.62 | 390 |
| 31–36 months | −0.92 | ±1.33 | −1.71 | ±1.89 | −3.21 | ±2.94 | 301 |

+ Indicates that the involved extremity is warmer than the uninvolved.
− Indicates that the involved extremity is colder than the uninvolved.

normal persons were made in only twenty-two instances, which permitted relative clinical comparisons, but were too few to validate statistical comparisons. The normal standards have been previously reported [16], and the technique of their development has been described. Under conditions of testing identical with those for the patients in this series, an average aggregate difference of 0.011 ± 1.14 degrees Fahrenheit was found to exist in the skin between the lower extremities in the normal individuals. The mean difference in the temperature of the gastrocnemius between the two limbs in the normal series was found to be 0.4 ± 2.11 degrees Fahrenheit. The mean differences at particular levels of skin in the normal series ranged from − 0.28 ± 0.005 to + 0.18 ± 0.008 degrees Fahrenheit. For analytical purposes, direct comparisons were made between the paralyzed and the normal series; and the Fisher t test was employed in evaluating the significance of any changes which were observed in the skin. This test allows any deviation of observed values to be compared with expected results in normal persons under the same circumstances.

## RESULTS OF MEASUREMENT OF SKIN TEMPERATURE

In order to analyze the alterations in temperature of the skin on the lower extremities of these patients with poliomyelitis, it was necessary to determine the amount of change which could be considered significant. The level of significant difference between the limbs of normal individuals was determined at 2.3 degrees Fahrenheit since this value corresponds to the ninety-fifth percentile (two standard deviations) of average aggregate difference in skin temperature. A consistent difference which exceeded 2.3 degrees Fahrenheit was therefore considered to be abnormal.

When the average aggregate differences in temperature between the normal and paralyzed limbs in these patients with unilateral involvement were analyzed, the influence of time following onset of the disease becomes apparent (Table I). Contrary to the findings of some observers [11, 14], we did not detect abnormal coldness during the first forty days of the disease[16]. In fact, the change observed in the first twenty days was that of increased warmth in the paralyzed extremity, but this was not of sufficient degree to warrant definite conclusions. However, during the first four months after onset of poliomyelitis, minor differences in skin temperatures did occur with some trend toward coldness. The average aggregate difference became definitely colder in all groups after six months following onset, and attained the greatest coldness during the period from thirteen to eighteen months. Throughout the remainder of the three years of observation, the degree of coldness in the paralyzed limb remained relatively constant, with some fluctuation at different intervals. Significant coldness first appeared seven to nine months from onset in the group with marked weakness. Changes were less apparent in the other two groups. These data indicate that the appearance of coldness in the paralyzed extremity is related to the passage of time after onset of poliomyelitis and to the degree of paralysis, being greater in the limb with severe involvement.

It is interesting to note that the time in which the paralyzed leg became really cold was during the period thirteen to eighteen months after onset. This corresponds to the second winter of the disease in the majority of instances since the peak incidence in the area where these patients reside occurs in late August and early September. These data corroborate a clinical impression that many patients with paralysis may first complain of coldness of the involved leg during the second winter of the disease and may experience less subjective discomfort in later years. Among many of the patients with severe paralysis, this interval coincided with their first exposure to cold, as the first winter was usually spent indoors, either at home or in the hospital.

Further analysis of the changes in cutaneous temperatures observed in this group of patients was undertaken by means of the t test *. For this method, a high level of significance was chosen in comparing the differences so that variables which could not be controlled might be minimized. A probability (P) of 0.05, corresponding to the ninety-fifth percentile, was selected so that there would be only five possibilities out of 100 that the mean values observed could be due to chance alone. Analysis by this criterion confirmed once more that significant coldness of the skin did not appear in the paralyzed extremity in our patients during the first forty days of the disease, with the exception of one isolated instance during the first twenty days in the *good* group (Table II). All groups showed significant vasoconstriction five to six months after onset and at all subsequent intervals of observation. The computed values of t suggested a direct relation of coldness to the degree of paralysis, although the actual values could not be compared to determine relative differences between the three groups because of different numbers of tests in each group. This method of analysis permitted comparisons only of the appearance of coldness in the paralyzed limb relative to expected values among normal persons.

The alterations in cutaneous temperature in relation to paralysis and duration of the disease were quite striking when depicted graphically (Chart I). There was a gradual increase of the average aggregate difference in cutaneous temperature of the extremities in all groups during the first eighteen months. After this interval, the degree of coldness remained relatively constant but differed in amount depending upon the severity of the paralysis. In patients with mild and moderate paralysis, the values for the upper extremes were roughly comparable, but after six months, in the group with severe paralysis, this value tended to be lower than that of the other groups. The values for the lower extremes in all groups emphasized the tendency toward increasing coldness with the passage of time; the degree of coldness was related to the amount of paralysis.

Although the chronological appearance of coldness in extremities with paralysis is brought out by the use of the average aggregate difference in temperature, the changes in the specific areas of the limb are important when the possible effects upon growth are considered (Table III). The pulp of the great toe showed no relative coldness of the paralyzed extremities, with minor exceptions, when analyzed by the t test. The lack of

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* $$t = \frac{M_s - M_n}{\sqrt{\frac{\sigma_s}{N_s} \quad \frac{\sigma_n^2}{N_n}}}$$

M = mean
s = sample
n = normal
$\sigma$ = standard deviation
N = number

TABLE II

Significance of Relative Coldness
on the Involved Extremities of 153 Patients Based on t Test

Relation of Observed Changes to Duration of Paralysis and Residual Muscle Power

| Time after Onset | Residual Muscle Power<br>Good<br>t | <br>Fair<br>t | <br>Poor<br>t |
|---|---|---|---|
| First year | | | |
| 1- 20 days | 2.13 | 0.27 | 1.02 |
| 21- 40 days | 0.06 | 0.23 | 1.46 |
| 41-120 days | 1.51 | 3.31 | 2.85 |
| 5- 6 months | 3.35 | 4.82 | 7.22 |
| 7- 9 months | 6.82 | 10.11 | 11.94 |
| 10-12 months | 6.01 | 8.13 | 10.71 |
| Second year | | | |
| 13-18 months | 7.49 | 12.65 | 18.40 |
| 19-24 months | 4.41 | 7.35 | 11.21 |
| Third year | | | |
| 25-30 months | 3.72 | 8.43 | 11.96 |
| 31-36 months | 4.99 | 7.76 | 10.66 |

t of more than 1.96 is significant for probability (P) = 0.05 (95th percentile).

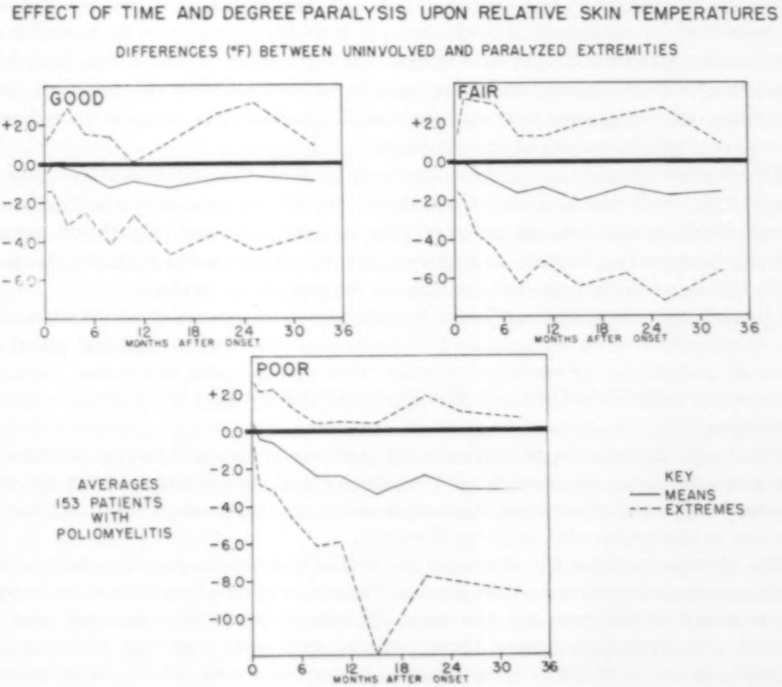

Chart I

## TABLE III

### Effect of Duration of Paralysis on the Relative Temperature of the Involved Lower Extremity at Seven Areas of Skin

Mean Differences in Temperature among 153 Patients Divided According to Unilateral Residual Paralysis

| Time after Onset | Great Toe | | | Dorsum of Foot | | | Medial Malleolus | | |
|---|---|---|---|---|---|---|---|---|---|
| | Good | Fair | Poor | Good | Fair | Poor | Good | Fair | Poor |
| First year | | | | | | | | | |
| 1– 20 days | +0.1 | +0.3 | $+\underline{3.5}$ | +1.5 | −0.1 | +0.8 | −0.2 | 0.0 | $+\underline{1.2}$ |
| 21– 40 days | +0.8 | +1.3 | +0.5 | +0.3 | +0.3 | +0.4 | +0.1 | 0.0 | −0.2 |
| 41–120 days | −0.6 | +0.8 | −0.1 | +0.3 | +0.7 | −0.2 | +0.1 | $-\underline{0.4}$ | −0.1 |
| 5– 6 months | −0.2 | +0.7 | 0.0 | −0.2 | +1.1 | −1.1 | $-\underline{0.7}$ | $-\underline{1.5}$ | $-\underline{0.8}$ |
| 7– 9 months | +0.1 | −1.2 | −1.0 | −0.7 | −0.6 | $-\underline{4.2}$ | $-\underline{1.4}$ | $-\underline{2.3}$ | $-\underline{2.6}$ |
| 10–12 months | $-\underline{2.1}$ | −2.0 | −0.6 | −1.7 | −0.4 | −1.6 | $-\underline{0.9}$ | $-\underline{1.2}$ | $-\underline{3.2}$ |
| Second year | | | | | | | | | |
| 13–18 months | $-\underline{1.6}$ | −0.5 | $-\underline{3.4}$ | −2.1 | $-\underline{2.1}$ | $-\underline{5.4}$ | $-\underline{1.5}$ | $-\underline{2.2}$ | $-\underline{4.2}$ |
| 19–24 months | −0.3 | −0.5 | −1.5 | −0.6 | $-\underline{0.9}$ | $-\underline{2.4}$ | $-\underline{1.2}$ | $-\underline{1.8}$ | $-\underline{3.4}$ |
| Third year | | | | | | | | | |
| 25–30 months | 0.0 | −0.7 | −1.3 | −0.5 | $-\underline{1.6}$ | $-\underline{3.9}$ | $-\underline{1.2}$ | $-\underline{2.4}$ | $-\underline{4.2}$ |
| 31–36 months | −0.4 | −0.2 | −0.7 | −0.7 | $-\underline{2.2}$ | $-\underline{4.0}$ | $-\underline{0.9}$ | $-\underline{1.4}$ | $-\underline{4.2}$ |

Underlined values are significant by t test (P = 0.05).

abnormal coldness in this particular site may be of importance since it is the area used solely in many instances as an index of the circulatory status in the lower extremity when measured by cutaneous temperatures. It is an area considered to be under greater control of the sympathetic nervous system than are other areas of the limb[4, 13]. Our observations over the period of testing appear to indicate that the toe does not show the evidence of vasoconstriction and decreased circulation in relation to poliomyelitis that is shown by other areas of the extremity.

The dorsum of the foot of the paralyzed limb showed significant coldness in the patients with moderate and severe paralysis, but at no time was abnormal vasoconstriction noted in this area on patients with mild involvement. Significant coldness at this level was noted at thirteen to eighteen months after onset in both the *fair* and *poor* groups, and this change persisted throughout the periods of testing.

The skin over the medial malleolus became significantly cold five to six months after onset of poliomyelitis in all groups, and cutaneous vasoconstriction was noted at this level in all patients at subsequent intervals. This was the area which was warmer than the normal by a significant amount during the first twenty days in the group with marked involvement.

Significant decrease in cutaneous temperature over the mid-portion of the shin was noted consistently in the groups with moderate and severe paralysis at all intervals following forty days after onset, and after seven months from onset a similar change was noted in the group with mild involvement.

The changes noted in the skin over the medial belly of the gastrocnemius muscle, at a point medial and posterior to the level of the mid-portion of the shin were comparable to those noted at the previous two sites. Significant coldness in the skin over muscle appeared very irregularly among those patients with mild paralysis. In those patients with moderate paralysis, abnormal coldness began five to six months after onset, while in the *poor* group, the change occurred even earlier, forty-one to 120 days after onset.

TABLE III (*Continued*)

EFFECT OF DURATION OF PARALYSIS
ON THE RELATIVE TEMPERATURE OF THE INVOLVED LOWER EXTREMITY AT SEVEN AREAS OF SKIN
Mean Differences in Temperature among 153 Patients Divided According to Unilateral Residual Paralysis

| Mid-tibia |  |  | Over Muscle |  |  | Tibial Tuberosity |  |  | Medial Femoral Condyle |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Good | Fair | Poor | Good | Fair | Poor | Good | Fair | Poor | Good | Fair | Poor |
| −0.8 | −0.4 | 0.0 | −0.7 | −0.1 | −0.3 | −0.2 | +0.6 | 0.0 | −0.1 | −0.1 | −0.8 |
| −0.4 | −0.9 | −0.6 | −0.2 | −0.2 | −0.7 | +0.2 | 0.0 | −0.7 | −0.2 | −0.3 | −0.5 |
| −0.5 | −1.2 | −1.2 | −0.7 | −0.5 | −0.9 | 0.0 | −0.8 | −0.8 | −0.3 | −0.6 | −0.3 |
| −0.4 | −1.6 | −2.4 | −0.7 | −1.2 | −1.7 | −0.5 | −1.0 | −1.4 | −0.5 | −0.8 | −1.2 |
| −1.1 | −2.1 | −3.0 | −1.3 | −1.8 | −2.6 | −1.0 | −1.6 | −1.6 | −1.7 | −1.1 | −1.6 |
| −1.0 | −1.8 | −3.1 | −0.8 | −1.4 | −2.2 | −0.5 | −1.4 | −1.9 | −1.0 | −0.9 | −1.3 |
| −1.0 | −2.7 | −4.2 | −1.3 | −2.0 | −3.2 | −0.6 | −2.2 | −3.1 | −1.1 | −1.4 | −1.5 |
| −1.2 | −2.1 | −3.4 | −1.0 | −1.4 | −2.5 | −0.7 | −1.1 | −1.6 | −0.5 | −1.0 | −1.5 |
| −0.9 | −2.6 | −4.8 | −0.5 | −2.2 | −2.5 | −0.8 | −1.7 | −3.0 | −0.8 | −1.9 | −1.8 |
| −1.3 | −2.4 | −4.8 | −0.9 | −1.6 | −3.8 | −0.7 | −1.8 | −2.5 | −1.4 | −1.9 | −2.3 |

Significant coldness at the proximal levels, namely the tibial tuberosity and the medial femoral condyle, was detected consistently five to six months after onset of the disease in the *poor* and *fair* groups. In the patients with moderate paralysis significant alterations appeared earlier at the medial femoral condyle. The individuals with mild paralysis demonstrated significant coldness only at irregular intervals at the tibial tuberosity, but consistently five to six months after onset at the medial femoral condyle. In most respects, the alterations in cutaneous temperature in the groups with severe and moderate paralysis were similar to those found at the ankle and in the mid-portion of the leg.

It seems apparent from these data that the cutaneous temperature becomes significantly cold following poliomyelitis in all areas except the great toe. The time of appearance of significant coldness is parallel in patients with moderate and severe paralysis, but those with mild involvement show changes which are much less constant and are of less degree. The appearance of cutaneous vasoconstriction is related to the duration of the disease and becomes consistently significant only after the disease has been present for five or six months.

## RESULTS OF MEASUREMENTS OF MUSCLE TEMPERATURES

Muscle temperatures are more difficult to obtain because of the discomfort and apprehension created by the insertion of needle thermocouples. Our results are based upon the observations in 188 patients with unilateral paralysis, of whom fifty-five were in the *good* group based on the degree of residual muscle power, sixty-three in the *fair* group, and seventy in the *poor* group.

The differences in temperature of the gastrocnemius muscle in the extremities of normal persons are more variable than the cutaneous temperatures so that standards of reference are more difficult to determine and evaluate. A difference of two standard deviations (ninety-fifth percentile) was again chosen for the limits of significance in this study of muscle temperatures among patients with poliomyelitis. This value was determined to be 4.2 degrees Fahrenheit.

TABLE IV

EFFECT OF DURATION AND RESIDUAL MUSCLE POWER ON
RELATIVE TEMPERATURE OF GASTROCNEMIUS MUSCLE

Mean Differences (in degrees Fahrenheit) between the Normal and Involved Extremities
of 188 Patients with Unilateral Paralysis Following Poliomyelitis

| | Residual Muscle Power | | | | | |
|---|---|---|---|---|---|---|
| Time after Onset | Good | No. | Fair | No. | Poor | No. |
| First year | | | | | | |
| 1– 20 days | −2.4 | 4 | −1.8 | 4 | −0.9 | 10 |
| 21– 40 days | +0.1 | 5 | −1.6 | 5 | −0.6 | 10 |
| 41–120 days | −1.0 | 11 | −1.0 | 3 | −1.5 | 11 |
| 5– 6 months | −3.7 | 2 | −4.4 | 3 | −4.6 | 5 |
| 7– 9 months | −0.6 | 2 | −4.3 | 1 | −7.1 | 2 |
| 10–12 months | +1.0 | 2 | −1.6 | 1 | −1.8 | 2 |
| Second year | | | | | | |
| 13–18 months | −2.0 | 4 | −5.7 | 4 | −8.9 | 12 |
| 19–24 months | −3.8 | 1 | −3.6 | 3 | −8.5 | 4 |
| Third year | | | | | | |
| 25–30 months | −0.9 | 7 | −3.9 | 7 | −8.8 | 8 |
| 31–36 months | −0.9 | 4 | −4.8 | 2 | −10.7 | 9 |
| Fourth year | | | | | | |
| 37–48 months | −2.2 | 4 | −4.6 | 4 | −5.0 | 3 |
| Fifth year | | | | | | |
| 49–60 months | −2.3 | 10 | −3.7 | 12 | −8.0 | 19 |
| Five years or more | | | | | | |
| 61 months or more | −1.6 | 62 | −4.7 | 67 | −8.8 | 60 |

+ Indicates that the involved extremity is warmer than the uninvolved.
− Indicates that the involved extremity is colder than the uninvolved.

In the group of patients with mild paralysis no significant difference in the temperatures of the gastrocnemius muscle was found at any time during their illness (Table IV). When moderate and severe paralysis was present, the muscle of the involved extremity became significantly cold five to six months after the onset of poliomyelitis. In the patients with severe paralysis, coldness of significance persisted in the muscle throughout the remainder of the period of observation of five years or more, except for a single finding in two patients. The same tendency toward significant coldness in the muscle was observed in the patients with moderate paralysis, although exceptions to this pattern occurred.

The appearance of significant coldness in the gastrocnemius muscle of the patients with poliomyelitis compared closely with the appearance of significant decrease in temperature of the skin. Significant coldness appeared in both skin and muscle at five to six months in the patients in the *fair* and *poor* groups, and in both areas the influence of time after onset and the degree of paralysis is apparent. The fact that significant coldness does not occur in the muscle of patients with mild paralysis is of great interest since inhibition of the growth of the long bones is seldom a problem in this group. On the other hand, the patients with moderate and severe paralysis who do show this abnormal coldness ordinarily demonstrate inhibition of growth of the long bones to varying degrees.

## COMMENT

Considerable confusion is found in the literature regarding the effect of poliomyelitis upon the peripheral circulation. Some of this may arise because of differences in techniques of measurement which are difficult in execution and interpretation. In none of the investigations reported by others have serial observations been made on the same patients over the period of time such as were carried out in this experiment. The intervals of time reported in this study tend to eliminate any difficulties of interpretation as to what constitutes the acute, convalescent, and chronic stages of the disease.

There are some [2, 11] who feel that peripheral vasoconstriction is present during the acute and early convalescent phases of poliomyelitis. In several of their studies, oscillometry was used as a measure of the degree of circulatory changes, but this method has the disadvantage that the range of normal is great and the method has sometimes failed to show circulatory change in the presence of severe vasoconstriction associated with soft-tissue atrophy [3, 12].

Our results, from using skin temperatures measured under controlled conditions as an index of peripheral circulation, indicate that significant cutaneous vasoconstriction is not present during the acute stage of the disease. A corresponding lack of change in the muscle temperatures was noted in these same patients. Such findings have been described by certain observers [1, 7] who failed to observe vasoconstriction early in the disease when measured by cutaneous temperatures and plethysmography.

During the early phases of the disease, isolated instances of vasoconstriction may arise at various areas of skin. However, these alterations are not consistent and are probably not of great moment. Likewise, significant warmth may occasionally be noted during the first four months of poliomyelitis, but the changes are not sufficient to indicate any primary involvement of the sympathetic nervous system.

Vasoconstriction, of a significant degree, does occur in the skin and muscle during the convalescent and chronic stages of the disease. According to our data, coldness of the skin and muscle is related to the degree of paralysis and is related to the time which has elapsed since the onset of the disease. Significant changes in the cutaneous circulation that show a consistent behavior do not occur until five to six months after the initial stages of the illness. The same was true in muscle which showed more dramatic changes than did the skin. The group of patients with severe paralysis showed the greatest absolute coldness and the greatest coldness relative to the temperature of the uninvolved side. Conversely, the least degree of coldness in both skin and muscle occurs in the patients with mild paralysis. Several observers have indicated [10, 15] that the degree of vasoconstriction and coldness is not directly related to the amount of paralysis. Our data indicate that a direct relationship exists between the degree of coldness and the extent of paralysis when mean values are considered. It is true that coldness and paralysis did not always show such direct relationship in a few individual instances, but these isolated cases did not influence the mean values of any of the three groups.

Peripheral circulation is frequently assessed by measurement of the temperature of the skin on the great toe. Because this area appears to be rich in arteriovenous anastomoses and under control of the sympathetic nervous system to a greater degree than other areas of the limb [9], it has been used to determine alterations in peripheral circulation due to nervous influences. In this area our data fail to reveal any significant alterations in circulation either early or late that may be ascribed to poliomyelitis.

All evidence suggests that the observed coldness and circulatory changes are not a primary effect of the disease upon the sympathetic nervous system. The absence of early changes in the temperatures of skin and muscle and the development of coldness and circulatory changes only after a considerable interval following the onset of the disease are the strongest evidences for this. The lack of response in the great toe either early or late is further evidence.

That the major feature of the circulatory change in these persons is vasoconstriction has been demonstrated in various ways. The colder involved extremity is capable of vasodilatation and on reflex vasodilation test reaches a level of warmth comparable to the normal side [17]. Similarly, the circulation of the skin and muscle in the affected limb will respond in a normal manner by vasoconstriction to applied cold. All this would indicate that the sympathetic nervous supply is intact after poliomyelitis, and by some mechanism the vasoconstrictor tone of the peripheral blood vessels is increased.

This increased vasoconstriction affects the vessels of both the skin and muscle. A divergence in response to various stimuli with respect to cutaneous and muscle circulation has been noted by several investigators [5, 6, 18]. However, our data on these patients with poliomyelitis indicate that the vessels in both skin and muscle behave in a similar and comparable fashion to the reflex vasodilation test and to applied cold [17].

The mechanism by which the chronic vasoconstriction occurs is not clear. It would seem reasonable that it is a response to diminish the blood flow into an extremity which has a decreased muscle mass with associated disuse, reduced vascular requirements, and a lowered efficiency of venous return due to the paralysis of skeletal musculature. Whatever the mechanism it would appear to be a reflex phenomenon in which the afferent stimulus giving rise to vasoconstriction has not been demonstrated. The vasoconstriction requires time to develop and is not an immediate effect of paralysis. Its degree tends to parallel the extent of the paralysis in the area.

## SUMMARY

1. Serial observations of cutaneous and muscle temperatures were made on patients with paralysis of one lower extremity only to ascertain the chronological appearance of changes in its peripheral circulation after the onset of poliomyelitis.
2. The data were subjected to statistical analysis for the determination of the significance of the alterations in circulation which were found.
3. Significant vasoconstriction in the skin of the paralyzed extremity was not present during the acute phase and appeared only after five to six months from the onset of the disease.
4. When vasospasm first appeared, it was minimal and sporadic; but after six months of the disease, the extremities of those with *poor* and *fair* muscles became consistently colder. The only exception in the distal portion of the extremity was the great toe which did not follow the circulatory pattern of the remainder of the extremity.
5. In the paralyzed muscle significant coldness appeared five to six months after onset of poliomyelitis in those groups with moderate and severe paralysis but was not present at any time in the group with mild paralysis.
6. Coldness of skin and muscle showed definite relationship to degree of paralysis.

Note: This study has been assisted by Dr. Thomas Gucker III, and Miss Margaret Anderson, as well as by Miss Margaret Bernsau, and Miss Jean Flynn, technicians (1943–1953).

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# Flexor-Tendon Injuries of the Fingers and Thumb

## A Comparative Study*

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During the past several decades there has been considerable improvement in the results of tendon surgery in the hand, and a consequent increase in the reported series of cases. Flexor-tendon injuries, especially in the "no-man's land" of Bunnell (Boyes' "critical" zone), continue to present considerable hazards to both surgeon and patient with frequent unsatisfactory results. The surgical practice in this group of patients was usually immediate primary repair of tendons, whenever possible. Secondary repair was performed only when the amount of associated trauma was too great to allow primary repair with any hope of success. Grafting procedures were reserved for those patients in whom a portion of the tendon was lost or in whom there were poor results after initial surgery.

Tendon-grafting has been used as a secondary procedure to correct unsuccessful repairs for a number of years with generally good results. In recent years, there has been increased use of grafts as the sole procedure for flexor-tendon injuries within the flexor tunnel. Grafts have been utilized not only as a delayed procedure after primary skin closure [1,4] but also even as a primary operation at the time of injury [5].

Dissatisfaction with the functional results following primary repairs has stimulated a review of all flexor-tendon injuries seen by the senior author over a four-year period. We have attempted to compare these objectively with other reports of flexor-tendon repairs, both primary repairs and grafting procedures, which have appeared in the recent literature.

The primary purpose was to determine whether a change in the basic approach to flexor-tendon injuries seemed indicated on the basis of current progress and to determine whether our results, with current techniques, paralleled other clinical reports.

A modification of the evaluative methods of the results is also presented. This modification in grading results seems to offer some advantages to the authors and it is hoped that it may prove useful to others.

### MATERIALS AND METHODS

This paper reports sixty tendon repairs in fifty-two patients. Twenty-one of these were in the thumb, and thirty-nine were in the fingers, of which sixteen were in the flexor tunnel and twenty-three outside the tunnel. All procedures were primary repairs and there were no infections in the series. The general principles of tendon surgery as outlined elsewhere [3,8,9] were followed. None of the injuries was over six hours old at the time of repair. The technique of the Bunnell pull-out wire was used except twice, when the injury was outside the flexor tunnel. Silk was used in these instances. Flexor digitorum sublimis tendons, when severed, were cut short and the fascial tunnel was incised or completely removed. Postoperatively the hands were splinted to relax the tendon with both the fingers and wrist in moderate flexion. Pull-out wires were usually removed at the end of three weeks, after which the patient resumed active motion.

The published series used for comparative purposes have appeared during the past ten years [2,5,6,7,9]. The statistical results from two series by the same author [6,7] were combined to make one line on the graphs. The results of 250 tendon repairs were included in those used for comparison, of which 185 were in the flexor tunnel, thirty-two outside the tunnel, and thirty-three in the thumb. Thus, with the addition in this report of sixty tendon repairs, there is a total of 310 cases for comparison.

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* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 25, 1957.

### MEASUREMENT OF TENDON FUNCTION

The method of measuring flexor-tendon function as originally described by Boyes was used. This determines the distance which the tip of the finger lacks of touching the distal palmar crease. This criterion of function affords an easily measured, objective standard which can be recorded graphically for comparative purposes. Only those series which have used the same method or an approximation of it were used for comparison.

In the thumb, the range of active and passive flexion of the terminal phalanx was measured (Fig. 1). The percentage of complete motion represented in the comparative series of grafts was figured by comparing the degrees of active and passive motion. Because some of the thumbs in the present series had a certain amount of limitation of passive motion, they are recorded as the percentage of active motion as compared with the approximately 80 degrees of normal flexion at the distal joint. This method of recording results proved more accurate in the authors' series. Posch's series of primary repairs reported the degrees of impairment of flexion. This was transposed into per cent of "normal flexion" for comparative purposes.

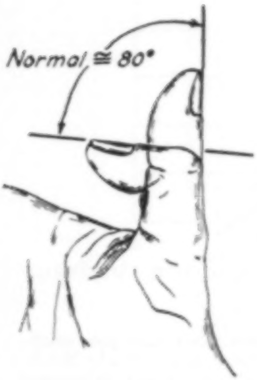

FIG. 1

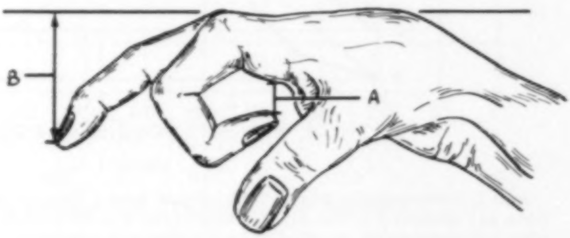

FIG. 2

Fig. 1: Drawing shows method of measuring flexion of the distal phalanx of the thumb, which is approximately 80 degrees in most normal hands. The frequency with which the passive range was no greater than the active range of motion in the present series seems to indicate that factors other than tendon function play an important role in determining how much motion will be regained following injury.

Fig. 2: Drawing shows method of measuring excursion of a finger. *A:* distance that the tip of finger lacks of touching the distal palmar crease. *B:* distance that the finger lacks of complete extension. *A* plus *B:* index of excursion as used in Chart IV.

### RESULTS

Chart I depicts the results of six series of repairs of finger flexors within the flexor tunnel. *Line 6* of the graph is the authors' series of primary repairs. There were no patients in this series who could touch the distal palmar crease with the tip of the finger. Thirty-eight per cent could come within one inch. Nineteen per cent fell between one and one-half inches, making 57 per cent that could come within one and one-half inches. Thirty-eight per cent fell between one and one-half and two inches, making 95 per cent that could come within two inches. The other lines on the graph are drawn from reports in the recent literature. *Line 1* represents a series of tendon grafts done as primary procedures at the time of injury. A larger percentage of these patients was able to touch the palmar crease, as compared with the percentage of those who could after other tendon grafts. This may be partly attributable to the decreased time of immobilization necessary

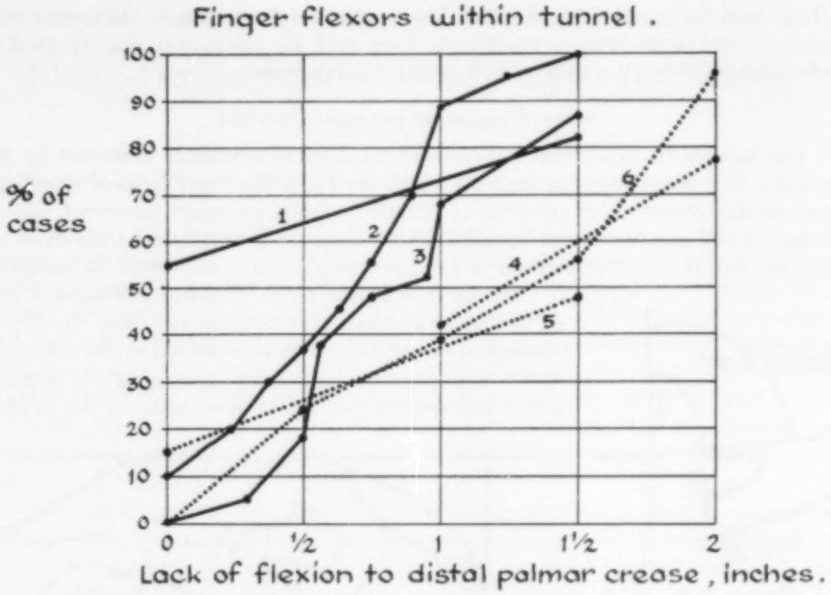

CHART I

*Line 1:* Primary grafts as reported by Flynn. *Line 2:* Delayed grafts performed under good conditions, as reported by Boyes. *Line 3:* Delayed grafts under average conditions, as reported by Boyes. *Line 4:* Primary repair, as reported by Jennings and associates. *Line 5:* Primary repair, as reported by Flynn. *Line 6:* Primary repair, present series.

The percentage figures in Charts I–IV are cumulative, so that for any designated amount of flexion lack, the percentage represents the total number of patients flexing to that point or less.

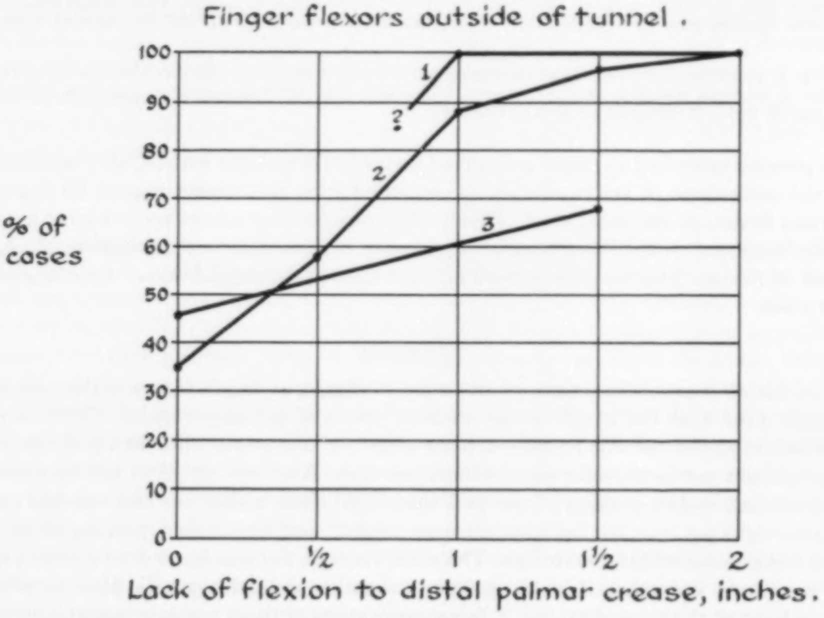

CHART II

*Line 1:* Jennings and associates' report of primary repair. *Line 2:* Primary repair, present series. *Line 3:* Primary repair, as reported by Flynn.

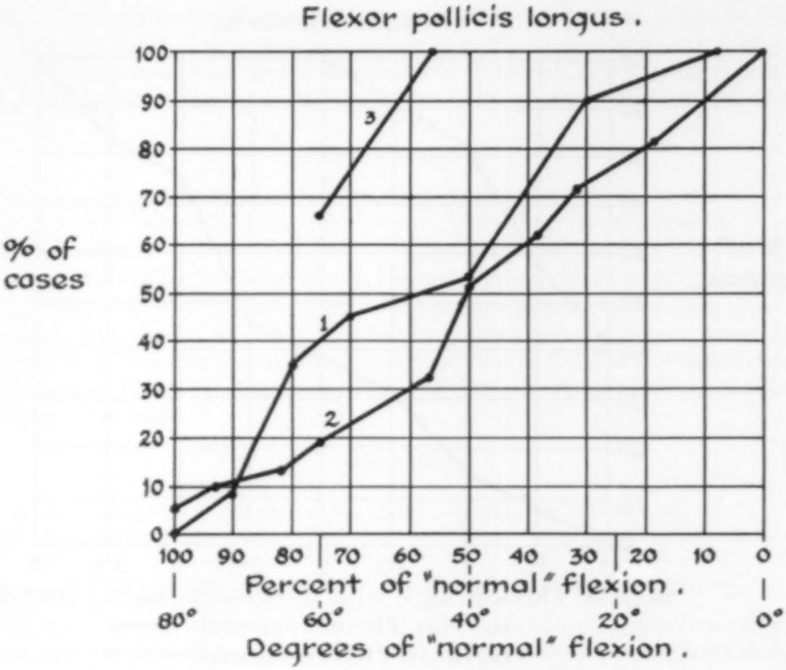

CHART III

*Line 1:* Delayed grafts done under good conditions, as reported by Boyes. *Line 2:* Primary repair, present series. *Line 3:* Primary repair, as reported by Posch.

with a single procedure, as against that required for a skin closure followed by a graft at a later date, or to the fact that a selected series is represented. *Line 2* represents a series of delayed tendon grafts done under good preoperative conditions. *Line 3* represents a series of delayed tendon grafts with an average number of preoperative complicating factors involved. Both of these groups had generally excellent results as compared with those obtained with the primary repairs. The S-shaped nature of the curve for the two series of delayed grafts (with those in the initial portion of the graph no better than the primary repairs) may reflect the frequency of complicating injuries to joints, nerves, and surrounding tissues, which inevitably hinders the last few degrees of flexion even with perfect tendon function. These curves suggest to us that finger flexion to the palmar crease may seldom be achieved in any unselected series of cases until the treatment of associated injuries has better results. *Lines 4 and 5* demonstrate the results of two other series of primary repairs, and are of approximately the same degree of success as the present series.

The repairs represented in Chart I were performed with pull-out wires of either the Bunnell or "barbwire" type, except for those in *Line 5* which were done with a variety of suture techniques. Variation in technique should not be a significant factor in producing the general over-all superiority of grafting procedures in these series.

Chart II shows the results of three series of primary repairs of finger flexors outside the flexor tunnel. *Line 2* of the graph represents the authors' cases. Thirty-five per cent of the patients in this group could touch the palmar crease. Fifty-two per cent fell between this and one inch, making 87 per cent that came within one inch. *Lines 1 and 3* show two other series of primary repairs. In the series represented by *Line 1*, all patients came within one inch of touching the palmar crease. A generally satisfactory outcome

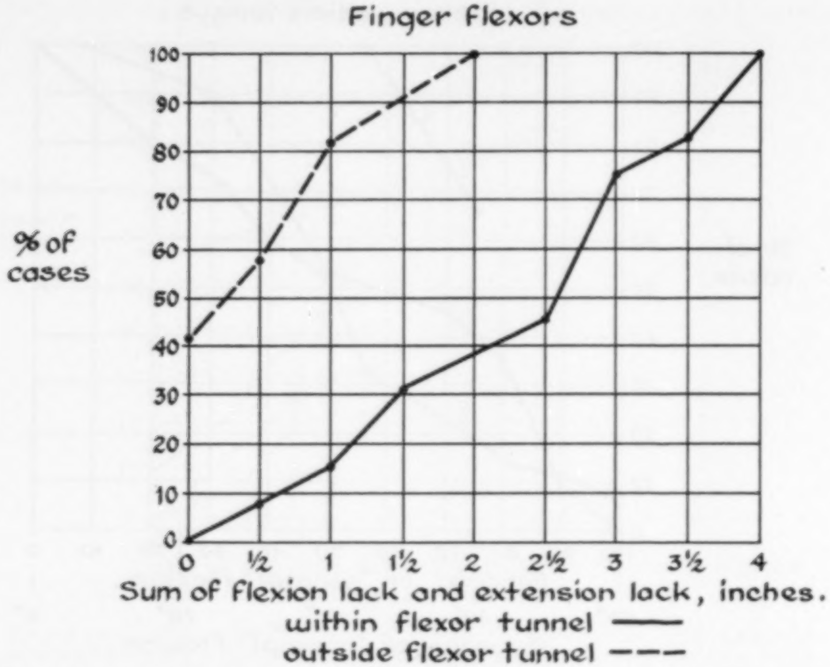

CHART IV

The numbers in this graph were obtained as shown in Fig. 2. This method of estimating the function of a finger following tendon repair is equally applicable to both flexor and extensor tendons. Index of excursion: 0–1 inches = Good; 1–2 inches = Fair; 2–3 inches = Poor; over 3 inches = Failure.

was the rule in all three groups. All of the repairs in the series shown in *Line 1* and all except two in *Line 2* were done with pull-out wires. The techniques used in the series shown in *Line 3* were not specified; presumably there was a variety.

Chart III shows results of two series of primary repairs of the long flexor of the thumb and one series of tendon grafts performed under good preoperative conditions. *Line 1* represents the tendon grafts and *Lines 2 and 3* the primary repairs. *Line 2* shows the authors' series. The better results of the primary repairs of *Line 3* are unexplained unless a significant variation in amount of associated trauma were present in the two series of primary repairs. Functionally the results are not a great deal different and are better in all series than the "percentage of function" figures would indicate. Considerable loss of flexion of the terminal joint of the thumb can be tolerated with little functional handicap to the patient.

### MODIFIED MEASUREMENT OF RESULTS

Chart IV indicates the results of the authors' series of finger flexors as recorded by a slightly different method. The change was made in order to apply to the occasional patient who had some limitation of both flexion and extension following repair of a divided tendon. Limitation of the opposite motion was observed after both flexor-tendon and extensor-tendon repairs, because of some degree of joint disability or scarring associated with the original trauma. Because two patients having the same amount of flexion lack, but differing in their ability to completely extend the finger, are not quite functionally equivalent, it seemed convenient to have a single figure reflecting this difference. After some consideration of the possibilities it was decided that the figure representing the sum of the amount of flexion and extension lack, measured as shown in Figure 2, would give the index of excursion in a simple manner. As this figure involves multiple factors, it would seem more useful in evaluation of over-all finger function, but not as valid in consideration of tendon function alone as the single measure of lack of flexion.

## CONCLUSIONS

Graphic comparison indicates that the results of grafts within the flexor tunnel are distinctly better than those of primary repair. The relatively poor results of primary repair would seem to indicate that grafting procedures might be preferable in the treatment of injuries within the flexor tunnel. However, the results of primary repair outside the flexor tunnel and of the flexor pollicis longus are markedly better than those within the tunnel. The shorter period of disability following primary repair would seem to justify the continued handling of those injuries outside the flexor tunnel and of the thumb in this manner. Grafting remains available for the severely traumatized wound, or to correct the poor result.

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## DISCUSSION

Dr. J. Leonard Goldner, Durham, North Carolina: The authors make a specific distinction between lacerations of the flexor tendons which occur within the annular ligaments and those which occur outside of these heavy bands. If the injury occurs within the limits of the annular ligament and primary repair is done, a satisfactory range of flexion and extension at the interphalangeal joints usually, in the adult, cannot be expected. Recall the alteration in function that occurs with simple trigger-finger and it will be clear that minor distortion of the relationship between the tendon and the annular ligament will limit both flexion and extension. The results of primary repair in this area are not completely satisfactory in either adults or children and the authors' premise that lacerations in the palm within the annular ligament should be treated by a delayed method agrees with my own experience.

One must ask how far the annular ligament extends into the finger. There is only a small area in the region of the proximal interphalangeal joint where the tendons are outside of the heavy tunnel, and this should be the only location where a suture might be done. However, complications do arise in this region because of the insertion of the sublimis, the location of the suture line opposite a moving joint, and the narrow area available for swelling and healing. Furthermore, the position of the finger at the time of laceration will affect the location of the suture line even if the ligament is excised. This implies that a laceration within the confines of the annular ligament, from the distal crease in the palm to slightly beyond the distal crease in the fingers, should not be repaired by primary suture.

In my opinion, primary repair should be attempted only if the laceration is proximal to the annular ligament in the palm and if the injury occurred while the fingers were extended. Advancement procedure should be attempted in the finger if the injury is in the region of the distal crease and if the fingers were flexed at the time of injury. If other factors overrule the advisability of primary treatment, closure of the skin may be done with confidence in the fact that a delayed primary procedure in three weeks will give a result as good as that obtained from primary advancement in the finger or primary suture in the proximal region of the palm.

The decision as to when to do the tendon surgery will be influenced by (1) location of the skin laceration; (2) position of the finger at the time of the laceration; (3) extent of the soft-tissue and bone injury; (4) the age and general condition of the patient; and (5) the amount of time that has elapsed from the injury to when the patient is seen.

The authors have included injuries of the thumb in the same category as injuries of the fingers. Tendon lacerations in the thumb are not the same as those in the fingers, either in their effect on the anatomy or in the end result of their repair. The thumb allows considerably more room for error. Limitation of motion at the distal interphalangeal joint and even at the metacarpophalangeal joint of the thumb does not handicap hand function as does the limitation of motion in a finger. If the surgeon must do a primary repair, let him do it in the thumb rather than in a finger. However, even the end results of thumb repair are far from ideal if the suture line is directly opposite the metacarpophalangeal joint or opposite the proximal phalanx. If the proximal end of the tendon can be located easily at the time of the initial laceration and if adequate length is available, advancement followed by lengthening of the tendon at the wrist is a satisfactory procedure. Direct tendon-to-tendon suture as far distally as possible, followed by excision of the annular ligament, may also be done if the surgeon decides against delayed primary repair or advancement.

The average surgeon may treat only a few fresh flexor-tendon lacerations each year. A surgeon who is dealing with trauma may see many more, but the majority of these are associated with extensive skin damage and fracture. Most of the patients I see have already undergone an attempt at primary tendon repair, or have had severe trauma accompanied by tendon laceration, and an effort has been made to repair the tendons because they were visible in the wound. If primary repair or suture of the tendon has not been attempted, the secondary procedure, whether it be a free tendon graft or a delayed primary suture, is much easier.

The authors' index of excursion is not shown pictorially enough. It does suggest how close the finger tip is to the distal palmar crease, but it does not give an absolute measurement as does Boyes' method which measures exactly the distance of the finger tip to the distal palmar crease. If Boyes' method were followed carefully, both in measurement and in taking photographs, end results could be determined a little easier. The photograph which shows the finger tips touching the thenar and hypothenar eminences with the metacarpophalanageal joint flexed to 90 degrees does not indicate an excellent result since arthrodesis of the proximal interphalangeal joint with good knuckle-joint motion may result in a hand with the same appearance. In determining range of motion of individual fingers, the adjacent digits should be flexed to the palm and the involved finger should be examined or photographed first in extension with the other digits still on the palm, and then in flexion without the aid of the adjacent digits pulling the involved finger into the palm. In this way or by describing the range of motion in this position, we get a true index of the actual range of motion at the interphalangeal joints.

In conclusion, it is my opinion that the average surgeon in the usual case may assure himself that a delayed primary repair if feasible, a free tendon graft if necessary, or a delayed or primary advancement procedure will give a digit with function superior to that obtained by primary repair of a lacerated flexor tendon in the distal portion of the palm or proximal portion of the finger.

**Dr. Joseph H. Boyes, Los Angeles, California:** I hope that Dr. Van't Hof's paper will be widely read and that its conclusions are carried into practice. Unfortunately I doubt that either will occur, for the average surgeon looks upon a flexor-tendon repair as minor surgery to be delegated to the most junior intern on the staff. If one studies all of his cases and evaluates them critically as has Dr. Van't Hof, I venture to say that the results will not compare favorably with his.

The ultimate test of tendon surgery is the repair in "no-man's land." Out of sixteen patients, Dr. Van't Hof reported that 43 per cent, or nearly one-half, lacked one and one-half inches or more of touching the distal crease of the palm. In no instance was there complete flexion. Comparable studies as recorded in the literature show even poorer results. In a series of twelve primary repairs in "no-man's land" done by my associate, Dr. James N. Wilson, one patient flexed his finger completely to the distal crease of the palm. The others fell into the same pattern of results as Dr. Van't Hof showed.

Since primary repair, even in selected cases, and all of these were selected, is not the answer to this problem, Dr. Van't Hof compared the results to those after tendon grafting. His studies show that secondary grafts are better but also indicate that primary tendon grafting is the best. Yet even here I wish to point out a fallacy in the comparison. The results of eleven primary grafts (Flynn's report) done in a highly selected group which had "wound(s) . . . clean and incised, with no element of avulsion or crushing," were compared with my report of 104 secondary grafts done for all kinds of conditions with four different techniques and over a period of ten years. Yet in the primary-graft series, 27 per cent of the fingers lacked one and one-half inches of flexing to the distal crease. If we take a comparable group of secondary grafts done under ideal conditions, the difference is even more striking, as it can be shown[a] that 25 per cent of the fingers in these cases flex completely, and that all flex to within one inch of the distal crease of the palm. Thus, judging from results shown in the records, it would be better, even in the so-called ideal cases, to close the wound and to do a secondary graft as soon as the reaction from trauma subsides.

One other reason that primary grafting cannot be accepted is that it violates one of the fundamental

*(continued on page 322)*

# Metastatic Tumors of the Hand*

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Metastasis to the hand from a malignant tumor with its primary source elsewhere is recognized as an uncommon occurrence. The literature contains a number of case reports and references to the subject, and several texts point out that metastases below the elbow are rare[3,5,12,17]. It is the purpose of this paper to summarize the literature on the subject of metastatic tumors of the hand and to add seven additional case reports. It is also hoped to record some of the more salient features of this group of neoplasms and to discuss their differential diagnosis.

In a perusal of the literature, twenty-three cases of metastatic malignant growths in the hand were encountered. Clinical, roentgenographic, and histological data were sufficient in sixteen of the cases to indicate the primary site of the neoplasm, its secondary deposit, and to establish the diagnosis unequivocally. In the remaining seven cases only

TABLE I

SUMMARY OF TWENTY-THREE CASES OF METASTATIC MALIGNANT TUMORS OF THE HAND FOUND IN THE LITERATURE

| Case | Primary Site | Age | Sex | Metastatic Site |
|---|---|---|---|---|
| 1. | Right lung [14] | 47 | M | Left middle, proximal phalanx |
| 2. | Right lung [24] | 40 | M | Right fifth, proximal phalanx |
| 3. | Right lung [28] | 49 | M | Right fifth, distal phalanx |
| 4. | Left lung [9] | 65 | F | Distal phalanges, right and left thumbs and left fourth digit |
| 5. | Left lung [9] | 55 | M | Left thumb, distal phalanx |
| 6. | Right lung [26] | 59 | M | Right thumb, proximal phalanx |
| 7. | Left lung [4] | 60 | M | Left middle, distal phalanx |
| 8. | Left lung [16] | 58 | M | Left thumb, distal phalanx |
| 9. | Left lung [29] | 66 | M | Left fourth, middle phalanx |
| 10. | Right lung [2] | 45 | M | Left thumb, distal phalanx |
| 11. | Lung [3] | Unknown | Unknown | Finger, unspecified |
| 12. | Breast [18] | Unknown | F | Right third, fourth, and fifth metacarpals |
| 13. | Breast [23] | Unknown | F | Phalanx, unspecified |
| 14.† | Left kidney [11] | 45 | M | Left fourth, distal phalanx with eventual involvement of nine digits |
| 15. | Right kidney [13] | 66 | F | Right second metacarpal |
| 16. | Bladder [6] | 39 | M | Right thumb, distal phalanx |
| 17. | Uterus [21] | 59 | F | Left thumb, distal phalanx |
| 18. | Lymphosarcoma [15] | 42 | M | Right first metacarpal |
| 19. | Parotid gland [23] | 41 | F | Right, distal phalanx |
| 20.† | Right testicle [2] | 45 | M | Right middle, subungual region |
| 21. | Parotid gland [1] | Unknown | F | Right middle, distal phalanx |
| 22. | Colon [20] | Unknown | Unknown | Bones of both hands and feet |
| 23. | Prostate gland [27] | 60 | M | Phalanges both hands, sites unspecified |

† Soft-tissue metastases (the superior numbers indicate reference to the bibliography).

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* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 25, 1957.

brief mention was made of the fact that a metastasis to the hand was encountered and details are lacking.

No case of a primary neoplasm occurring in the soft tissue about the hand with secondary involvement of bone is considered in this review because this is extension by invasion and not by metastasis. In two of the cases, the metastases appeared in the soft tissue of the hand first, the underlying bone being only secondarily involved. In the remaining twenty-one cases, however, the metastasis was directly to the bone structure of the hand and any soft-tissue involvement was of a secondary nature.

The first record of metastasis to the soft tissue of the hand was found in the French literature in 1907 when a kidney neoplasm metastasized to the soft tissues overlying a phalanx and subsequently involved the osseous tissue [11]. The other case of soft-tissue involvement was that of a chorionepithelioma of the right testicle with subungual metastases to the right finger. Such a case is described three times in the literature[2,22,25] but appears to be the same case and is so considered here.

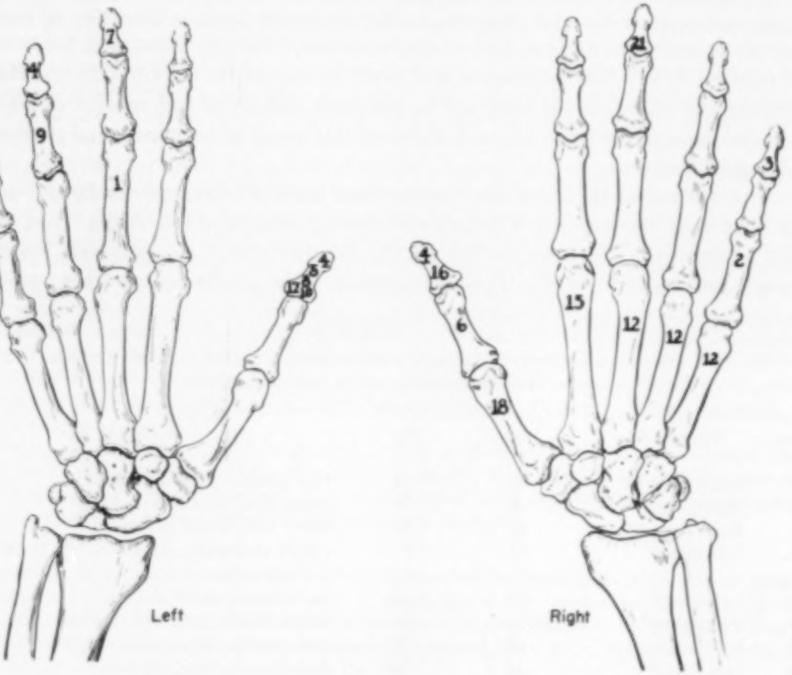

Fig. 1

Location of bone metastases to the hand in the sixteen cases that supplied the information. (The numbers correspond to case numbers listed in Table I.)

In 1906, the earliest mention of a metatasis directly to the osseous tissue of the hand appeared in the British literature [18]. The case of an elderly woman with carcinoma of the breast is presented, and multiple bone metastases to the metacarpals produced pathological fractures. This occurred before the use of roentgenograms and, at that time, pain or pathological fracture, or both, was a criterion of metastases to bone.

Credit for the first detailed American report of a metastatic lesion to the hand belongs to Floridis and associates who, in 1934, described a case of carcinoma of the lung with a phalangeal metastasis. One of the most remarkable cases noted was in the Czechoslovakian literature [21], where a metastatic lesion to the thumb of the left hand was described

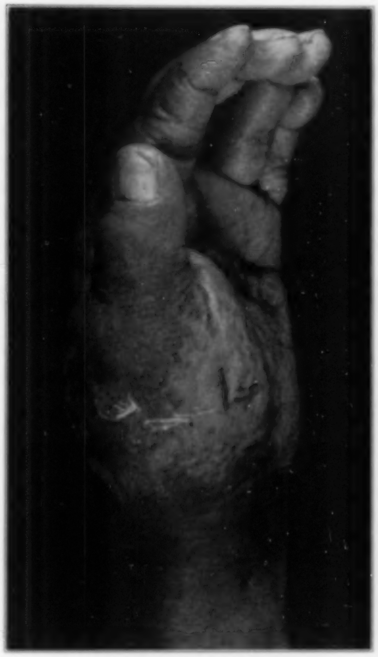

FIG. 2-A

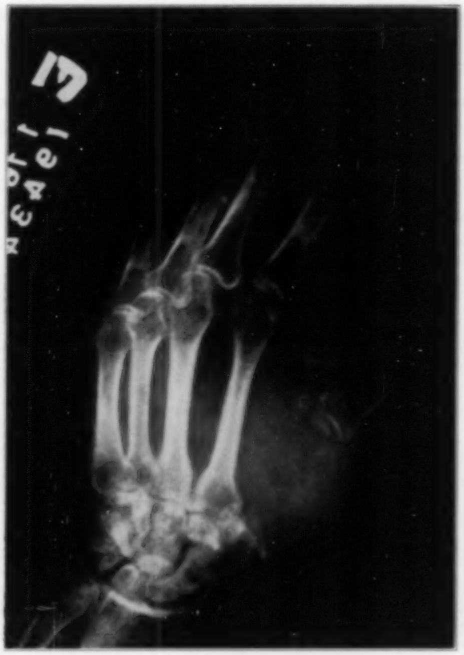

FIG. 2-B

Fig. 2-A: Case 1. On admission, this swollen, painful, draining hand was misdiagnosed as tuberculosis. The loss of pigmentation is probably due to the roentgen therapy noted in the history.

Fig. 2-B: Destruction of the entire first metacarpal bone has occurred. Note the preservation of the adjacent joints.

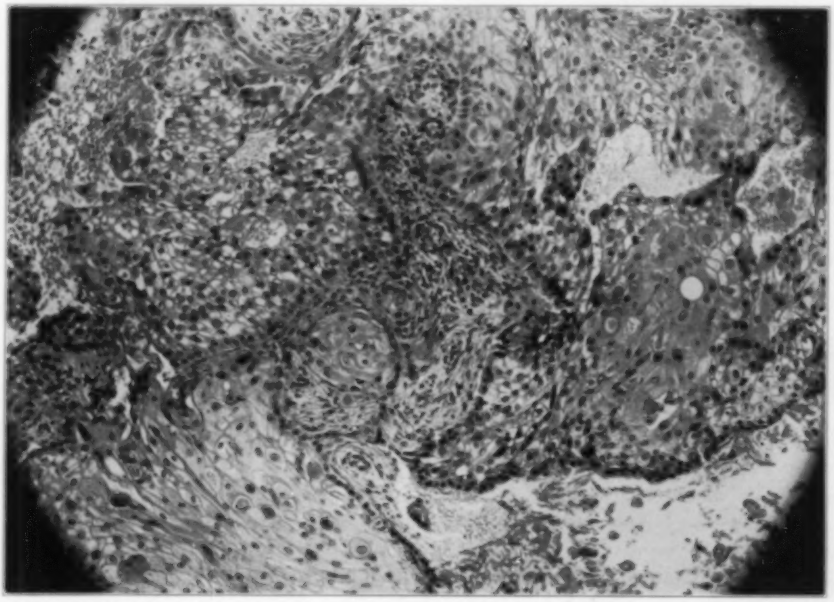

FIG. 2-C

Metastatic epidermoid carcinoma in first metacarpal, left hand, from bronchogenic carcinoma, left lung.

some thirteen years after the patient had had a hysterectomy because of carcinoma of the corpus uteri. Histologically, the primary and the metastatic lesions were similar.

A tabulation of the twenty-three cases of metastatic malignant growths of the hand found in the literature appears in Table I. Sixteen of the cases present data that make the diagnosis unequivocal, and in seven cases the clinical and roentgenographic data that were presented made diagnosis probable. Figure 1 illustrates the sites of bone metastases in the sixteen cases. It is of interest to note that the terminal phalanges were involved ten times, whereas the middle phalanges and proximal phalanges were involved twice each. All five of the metacarpals of the right hand were involved in a metastatic process while those of the left remained free. There was no recorded instance of involvement of the carpal bones.

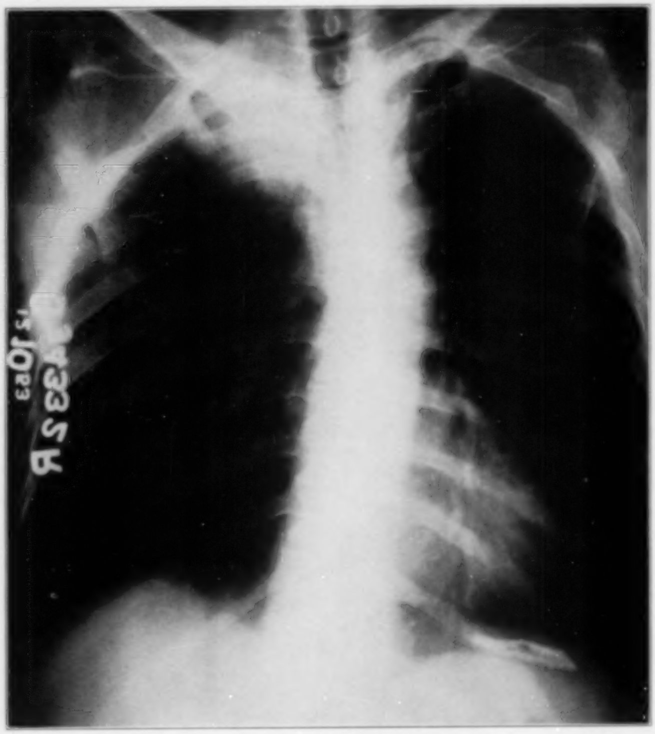

FIG. 2-D

Roentgenographically, the lesion in the right upper lobe has increased. Chest pain, cough, and dyspnoea, along with progressive weight loss also developed.

In the seventeen instances of recorded age, the youngest patient was thirty-nine; the oldest, sixty-six years. The mean age was fifty-three years. Males were afflicted more than twice as often as females, a finding that is not surprising in view of the fact that almost 50 per cent of the cases had their primary neoplasm in the lung.

Clinically, in a large number of cases an acute inflammatory lesion was the presenting complaint. Not infrequently the initial diagnosis was a whitlow, felon, or an acute osteomyelitis for which lesion the patient was treated. Only when the material was histologically examined was the true diagnosis recognized. In some of the patients in whom cancer of the lung was primary, the manifestations in the hand were the first indication of this otherwise silent neoplasm. In one instance, a pathological fracture through a metastatic area in the hand was the first indication of a pulmonary neoplasm [3]. The roentgenogram was instrumental in establishing the diagnosis in all but the earliest cases. The involved bone revealed a destructive process that often invaded the overlying soft tissue but seldom involved the adjacent joints.

Histological examination is the most desirable criterion to utilize in establishing the diagnosis. Of the cases in the literature, the primary site was evaluated in this manner eleven times, while microscopic examination of the metastatic area was reported to be carried out in sixteen cases. In seven cases the details were lacking.

The lethal implication that a metastatic malignant tumor to the hand carries is indicated by the fact that nowhere in the literature was the problem of therapy discussed. In all of the cases it was a foregone conclusion that death would supervene and some of the reports stated that the individuals were either dead or dying at the time of writing. It was observed, however, that in a number of reported cases, the metastatic deposit in the hand was the sole indication of any malignancy, and other metastatic foci were not observed either clinically or by roentgenographic examination of the skeletal system.

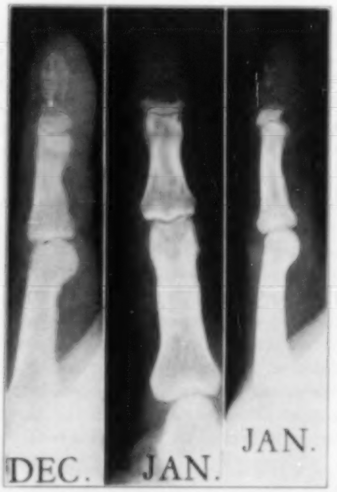

Fig. 3-A

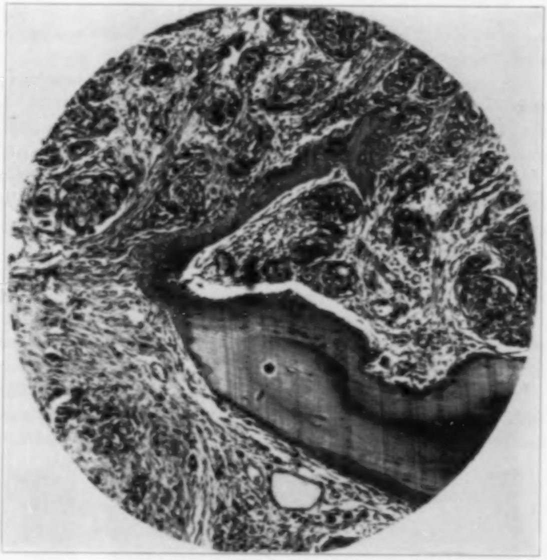

Fig. 3-B

Fig. 3-A: Case 2. Destructive lesion in the distal phalanx, right index finger indicating the progression over a period of a month.

Fig. 3-B: Metastatic epidermoid carcinoma to the distal phalanx of the right index finger, primary source in the lower lobe of the right lung.

A review of the records at the Bronx Veterans Administration Hospital, the Hospital for Special Surgery, and the New York Hospital, all in New York City, revealed that four cases of metastatic malignancy to the osseous tissue of the hand had been encountered. Two additional cases were encountered in Cleveland, Ohio, and the pertinent material in these six cases and in one furnished by Dr. Michael Lewin is summarized in the following case reports.

Case 1. A. S., a Puerto Rican male, fifty-eight years old, fell on his left hand approximately six months prior to his admission to the United States Veterans Administration Hospital, Bronx, New York. About six weeks later, he noted swelling and pain in his left hand just proximal to the thumb. He stated that he was treated at a hospital where a needle was inserted into the area followed by a few roentgen treatments, but he knew nothing further regarding the nature of his lesion. A review of systems revealed he had lost twenty-five pounds during the past six months but he voiced no pulmonary complaints.

*Physical examination:* Positive findings were confined to the left hand, where the region of the first metacarpal was oedematous and was the site of two open wounds draining purulent material. The surrounding skin revealed loss of pigmentation and hair, probably the result of the roentgen therapy noted in the history (Fig. 2-A). A few shoddy lymph nodes were present in both axillae. There was evidence of recent weight loss.

*Roentgenographic examination:* Except for preservation of the proximal and distal portions of the articular surfaces, the entire first metacarpal bone was destroyed by an osteolytic process (Fig. 2-B). The remaining bones in the hand were intact. A complete skeletal examination revealed no other lesions. A roentgenogram of the chest revealed an area of increased density in the apical region of the right upper lobe, suspicious of bronchogenic carcinoma.

*Course in hospital:* A curettage biopsy and drainage of the first metacarpal area were performed. Grossly, the curetted material consisted of soft, caseous, white material, some parts of which appeared necrotic and infected. Histological studies revealed metastatic epidermoid carcinoma (Fig. 2-C). Liver studies, pyelography, acid-fast studies, and bronchoscopy were non-revealing. As a symptomatic measure, amputation below the elbow was performed and the postoperative course was uneventful. The patient still had no pulmonary complaints.

About seven months later, however, the patient returned with pulmonary complaints and a roentgenogram of the chest revealed a large infiltrative lesion in the right upper lobe (Fig. 2-D). He was, at the time of writing, leading a progressively downhill course and the diagnosis was that of bronchogenic carcinoma.

Case 2. S. I., (patient of Dr. Karl Alfred) a white male, forty-seven years old, presented himself with a two-week history of pain at the tip of the right index finger. The patient was a professional accordion player and noted the pain especially while performing. There was no history of trauma of any kind.

*Physical examination:* Positive findings were confined to the right hand where the distal phalanx of the right index finger yielded tenderness upon compression. There was no increase of temperature, no swelling, and no discoloration. The rest of the physical examination was negative.

*Roentgenographic examination:* Roentgenograms revealed a destructive process localized in the terminal phalanx of the right index finger not involving the adjacent joint (Fig. 3-A). The other roentgenograms, including a skeletal survey and one of the chest, were within normal limits.

*Course in hospital:* An aspiration biopsy was done revealing a metastatic epidermoid carcinoma (Fig. 3-B). Disarticulation was accomplished at the distal interphalangeal joint. The wound healed by primary intention. A search for the site of the primary neoplasm failed to disclose it. Within six months the patient

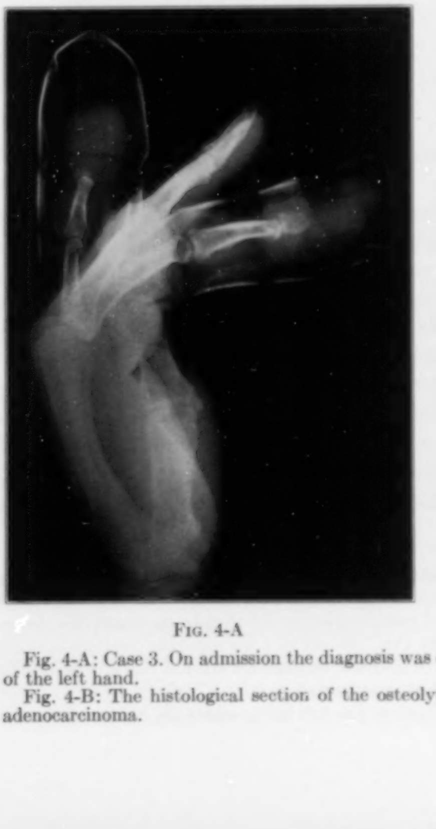

Fig. 4-A

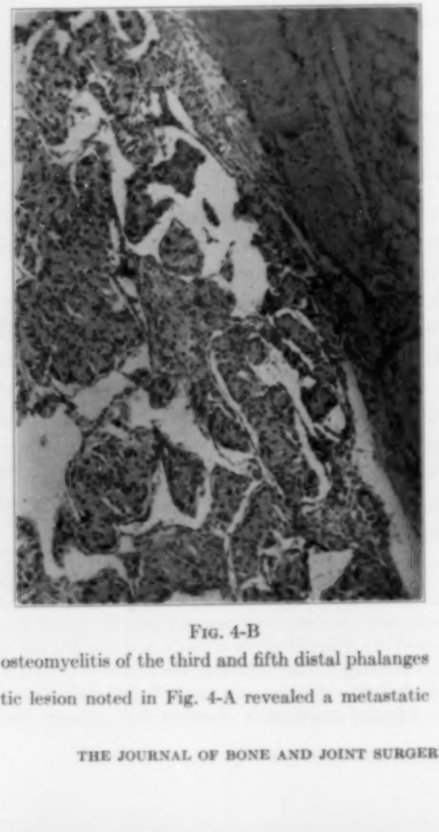

Fig. 4-B

Fig. 4-A: Case 3. On admission the diagnosis was osteomyelitis of the third and fifth distal phalanges of the left hand.

Fig. 4-B: The histological section of the osteolytic lesion noted in Fig. 4-A revealed a metastatic adenocarcinoma.

had pulmonary complaints; he died in July 1956. An autopsy revealed bronchogenic carcinoma of the right lower lobe of the lung, with metastases to both femora. It is interesting to note that in this case as in Case 1, the only manifestation of the silent neoplasm in the lung was a metastatic process to the hand.

CASE 3. A. A., a white male, forty-seven years old, was admitted to the Hospital for Special Surgery for the first time in February 1951, with pain and swelling over the tips of the middle and little fingers of his left hand. He could recall no injury to these fingers; however, three weeks previously he had struck the tip of his ring finger with a hammer. He gave no history of a previous focus of infection.

In a review of systems, the patient complained of an occasional cough, not associated with chest pain or bloody sputum. There was no history of weight loss and no gastro-intestinal or genito-urinary complaints.

Past history revealed that two years before (1949) "a small tumor underneath the skin" was excised from the anteromedial aspect of the left arm, which recurred four months later and was again excised. It recurred for the second time ten months later, and was excised for the third time at another hospital. The pathological report obtained from the hospital where the third excision was accomplished recorded the microscopic diagnosis of carcinoma of the dermal adnexa (sebaceous-gland carcinoma). At the time of his admission to the Hospital for Special Surgery, the tumor had not recurred during the previous four months.

*Physical examination:* Positive findings were confined to swelling of the terminal phalanges of the middle and little fingers of the left hand. Marked tenderness was elicited upon slight pressure over these areas. No discoloration was noted. There was a well healed scar over the anteromedial aspect of the upper arm and there were no palpable lymph nodes in either axilla. The admitting diagnosis was osteomyelitis of the distal phalanges of the left middle and little fingers.

*Roentgenographic examination:* Roentgenograms

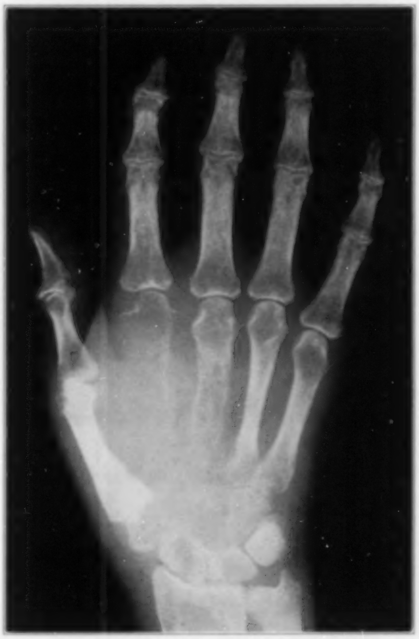

FIG. 5-A

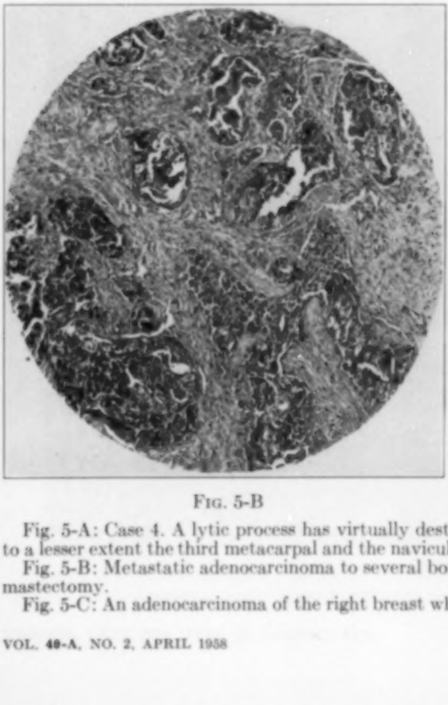

FIG. 5-B

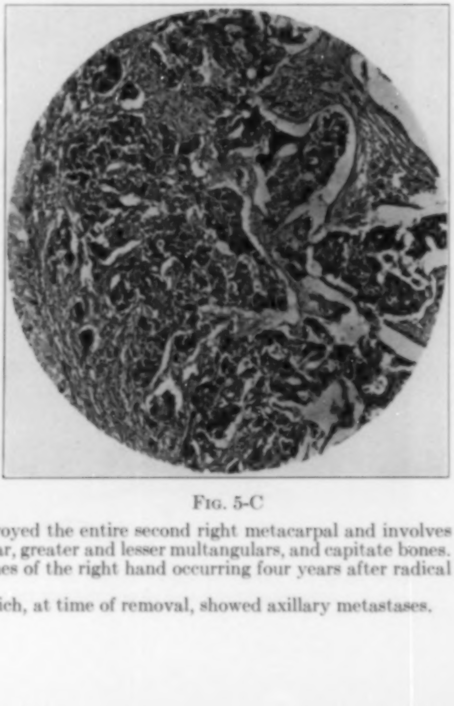

FIG. 5-C

Fig. 5-A: Case 4. A lytic process has virtually destroyed the entire second right metacarpal and involves to a lesser extent the third metacarpal and the navicular, greater and lesser multangulars, and capitate bones.

Fig. 5-B: Metastatic adenocarcinoma to several bones of the right hand occurring four years after radical mastectomy.

Fig. 5-C: An adenocarcinoma of the right breast which, at time of removal, showed axillary metastases.

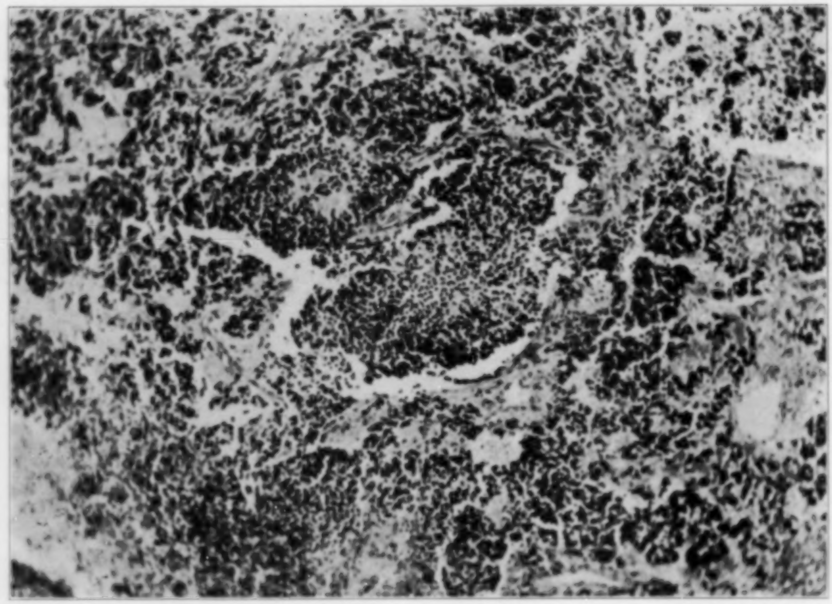

Fig. 6-A

Case 5. Section of a sympathicoblastoma, a primary tumor in the left adrenal gland in an eighteen-month-old baby.

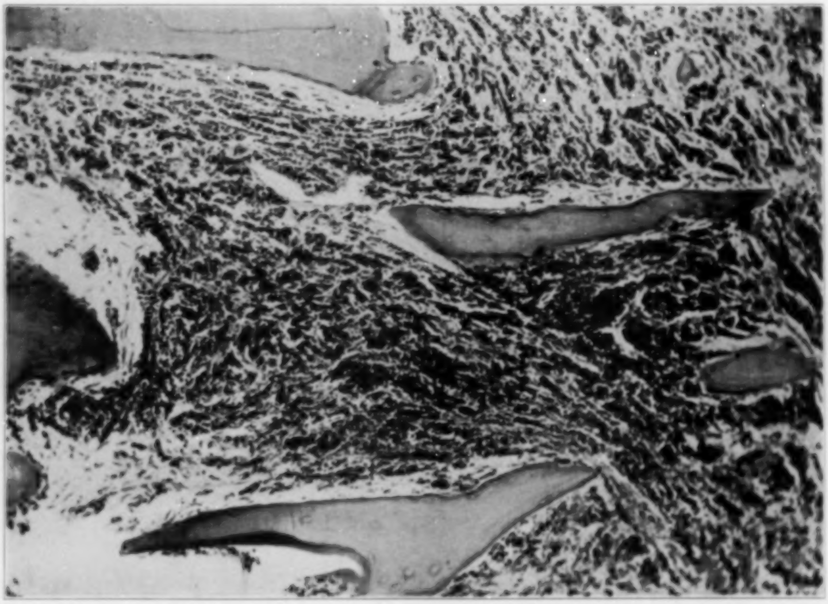

Fig. 6-B

Section of the metastatic deposit in bone, simulating the primary neoplasm.

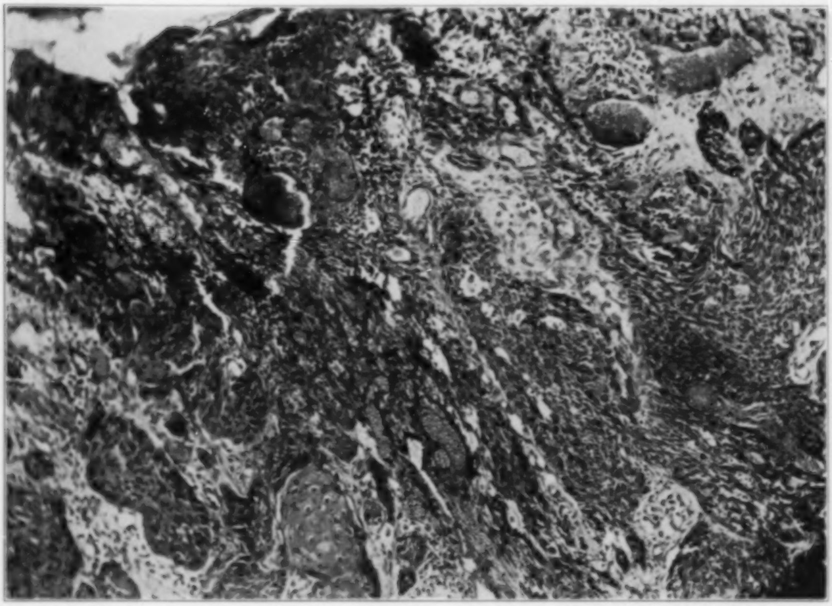

FIG. 7-A

Case 6. Section of epidermoid carcinoma from the skin of the plantar aspect of the right second toe in a seventy-year-old female.

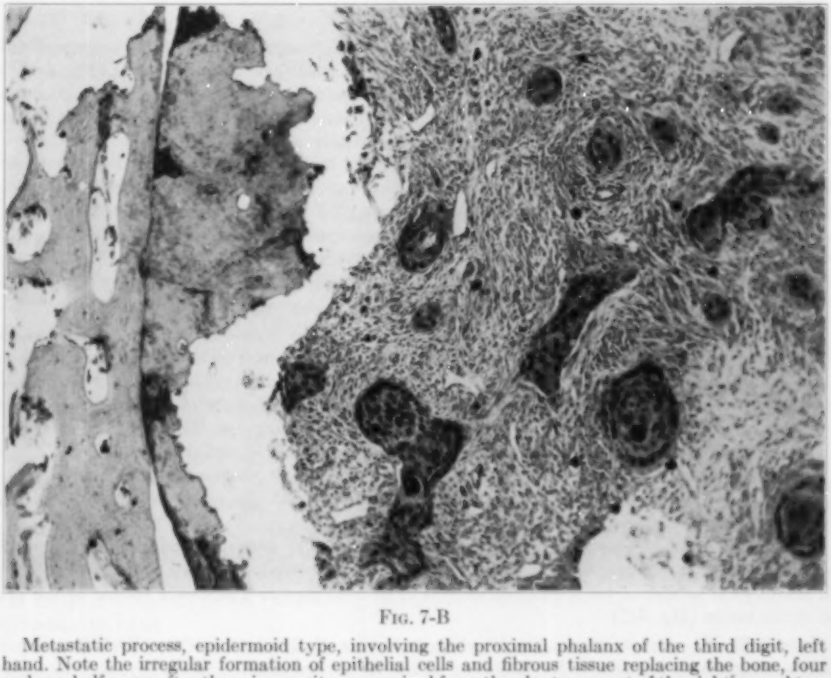

FIG. 7-B

Metastatic process, epidermoid type, involving the proximal phalanx of the third digit, left hand. Note the irregular formation of epithelial cells and fibrous tissue replacing the bone, four and one-half years after the primary site was excised from the plantar aspect of the right second toe.

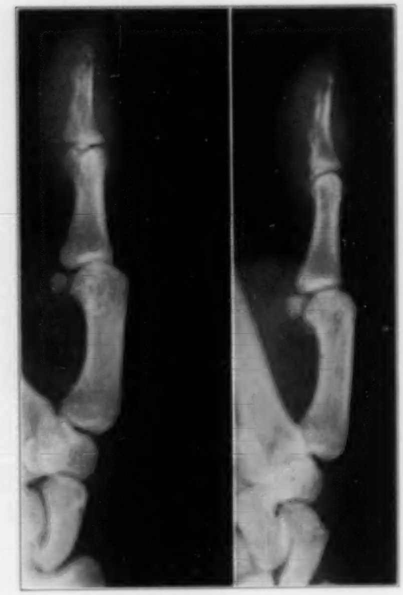

Fig. 8

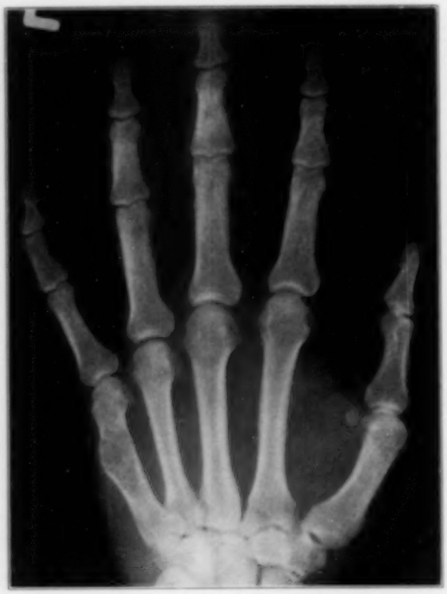

Fig. 9

Fig. 8: An osteomyelitic process characterized by lytic destruction of the distal phalanx. This is the lesion with which metastatic malignancy to the hand is most often confused.

Fig. 9: An enchondroma of the fifth metacarpal of the left hand. It has the usual characteristics including pathological fracture through its proximal portion (courtesy of Dr. Carroll Dundon).

revealed an osteolytic process involving the distal phalanges of the left middle and little fingers without involvement of the distal interphalangeal joint (Fig. 4-A). Findings in the left shoulder girdle, in the humerus, and in the chest were normal.

*Course in hospital:* An incision and drainage at the site of presumed osteomyelitis were performed on the middle and little fingers. The curetted material revealed a metastatic adenocarcinoma (Fig. 4-B). A few days later the middle and little digits were amputated through the middle phalanges. Subsequently, the patient was discharged with the understanding that he would undergo a complete examination to determine the primary site of the neoplasm. This was done at another institution.

*Follow-up:* A follow-up letter indicated that the patient had a mass in the right lobe of the thyroid gland, aspiration biopsy of which caused suspicion of renal carcinoma. Intravenous pyelography showed a mass in the left kidney. A roentgenogram of the chest revealed a mass in the basilar portion of the right upper lobe and within a few months the patient became hemoptic and dyspneic. Despite radiation therapy he went downhill rapidly, having cord metastases and paraplegia. He died in April 1952. The diagnosis considered most probable was adenocarcinoma of the left kidney with generalized metastases. No autopsy was performed.

Case 4. A. J. (patient of Dr. James Christie), a white female, sixty-two years old, had carcinoma of the right breast in 1951 treated by radical mastectomy. The axillary lymph nodes were involved. The patient did well until June 1955 at which time she noted swelling in the proximal portion of her left thigh. Roentgenograms revealed a destructive lesion involving the entire upper half of the right femur. It is not known how this was treated. In May 1956, she complained of marked swelling over the lateral aspect of her right hand. Examination revealed tenderness and moderately limited range of motion of the fingers.

*Roentgenographic examination:* Roentgenograms revealed a lytic process involving almost the entire second metacarpal, the proximal two-thirds of the third metacarpal, the navicular, greater multangular, lesser multangular, and the capitate carpal bones (Fig. 5-A).

*Course in hospital:* Histological evaluation of the destructive lesion involving the first metacarpal revealed a metastatic adenocarcinoma. The patient led a progressively downhill course and died in July 1956. Histological studies of the metastatic deposit (Fig. 5-B) showed a structure similar to the primary lesion in the breast (Fig. 5-C).

Case 5. W. T., an eighteen-month-old white male, was admitted to the New York Hospital with a tentative diagnosis of leukaemia. He had been sickly for several months previously, and was admitted to the hospital because of cough, diarrhoea, anorexia, and listlessness.

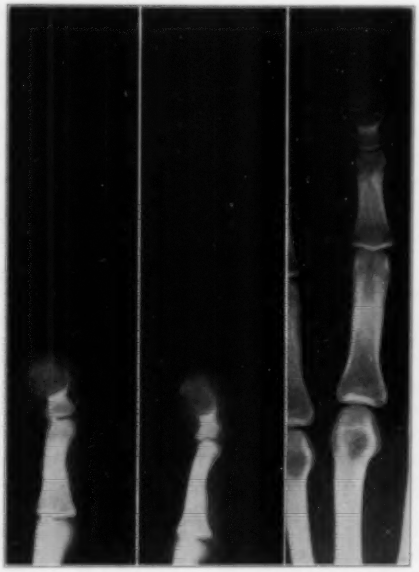

FIG. 10

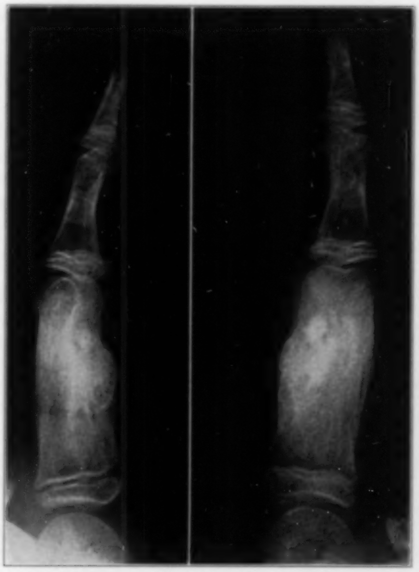

FIG. 11

Fig. 10: Epidermoid cyst within the distal phalanx of the third digit, right hand. Patient had a puncture-type injury twenty years previously and during the past six months had noted swelling and tenderness (courtesy of Dr. Carroll Dundon).

Fig. 11: Osteoid osteoma occurring within the proximal phalanx of the index finger of the right hand.

*Physical examination:* Examination revealed a poorly nourished and poorly developed baby who appeared acutely ill. He exhibited generalized lymphadenopathy, and moist rales in both lung fields, but was afebrile. On palpation, both the liver and spleen were found moderately enlarged.

*Roentgenographic examination:* A complete roentgenographic study made shortly after admission revealed that "almost every bone in the body presented a bizarre picture with a very marked generalized moth-eaten appearance." This included the small tubular bones of the hands and feet. Roentgenograms of the hands made a month later revealed a further increase in the destructive process of the tubular bones and, in addition, showed periosteal elevation. Attempted intravenous pyelography was unsatisfactory on two occasions.

*Course in hospital:* The patient led a progressively downhill course and died within two months of hospitalization. At autopsy, a rubbery hemorrhagic oval mass weighing 22 grams and measuring 4 centimeters in length was found compressing the left adrenal gland to the extent that very little normal tissue could be identified. The most widespread metastases were noted in the lungs, pancreas, liver, spleen, and the entire skeletal system. The cervical mediastinal, mesenteric, and inguinal lymph nodes were replaced by tumor. Microscopically, the primary neoplasm was diagnosed as sympathicoblastoma (neuroblastoma of the Hutchinson type) (Fig. 6-A), and histological studies of the osseous metastases showed a similar structure (Fig. 6-B).

Unfortunately, only the roentgenographic reports, not the films, are available at this date.

CASE 6. T. W., a seventy-year-old white female, was admitted to the New York Hospital with an indurated weeping ulcer on the plantar aspect of the right second toe of two years' duration. Biopsy revealed epidermoid carcinoma (Fig. 7-A), and amputation through the metatarsophalangeal joint of the second toe was performed. Two years later, the patient returned with a mass in the right groin. A biopsy disclosed metastatic epidermoid carcinoma of the inguinal lymph nodes which were excised locally. A course of radiation treatment was given over the right inguinal area. Two and a half years later (four and a half years after her first visit) she presented herself complaining of pain and swelling in the region of the proximal phalanx, middle finger, left hand.

*Physical examination:* A fusiform swelling of the entire left middle finger was most marked in the proximal phalanx, where, in addition, the area was described as blue and tender to touch. Motion was limited at the third metacarpophalangeal joint. The right second toe had been amputated but there was no evidence of local recurrence of the previous skin neoplasm. A well healed scar was noted in the right groin. There were no palpable lymph nodes and no evidence of recurrence.

*Roentgenographic examination:* Roentgenographic report described destruction of the proximal phalanx of the middle finger, left hand, with generalized decalcification of the entire hand. In this case, as in Case 5, the original roentgenograms have been destroyed and only the reports are available.

*Course in hospital:* An amputation of the middle finger through the third metacarpal of the left hand was performed after which the patient made an uneventful recovery. Examination of the specimen revealed the bone of the proximal phalanx to be almost entirely destroyed, just a thin shell around the periphery remained. The material replacing the bone was described grossly as a "cartilaginous mass of dead white tissue." Microscopically, irregular islands of epithelial cells and fibrous tissue replacing the bone were noted (Fig. 7-B).

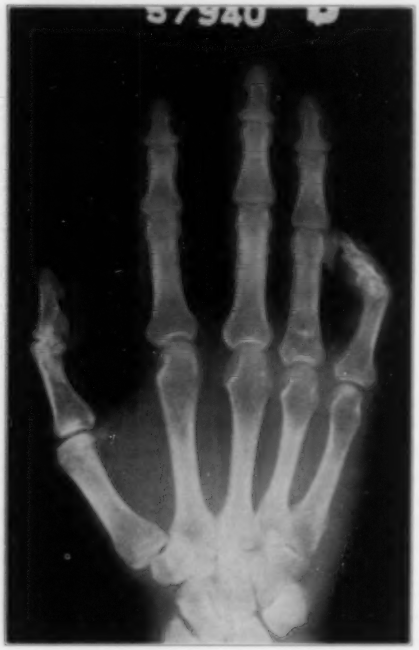

FIG. 12

Giant-cell tumor in the proximal portion of the proximal phalanx, fourth digit. Note the trabeculations within the cystlike defect (courtesy of Dr. Carroll Dundon).

*Follow-up:* Following discharge the patient complained of cough, chest pain, and intermittent bloody sputum. A roentgenogram of the chest revealed an area in the right lung field suspicious of a metastatic lesion. The patient became progressively worse. She was admitted to a nursing home for terminal care and died. The diagnosis in this case is metastatic epidermoid carcinoma in the proximal phalanx, left hand, the probable primary neoplasm being in the skin of the right foot. No autopsy was performed.

CASE 7. T. B. (patient of Dr. Michael Lewin), a white male, sixty-one years old, had an abdominoperineal resection for adenocarcinoma of the rectum in April 1953. There was recurrence of the lesion in 1955, and again in 1956.

It was noted early in 1956 that the distal phalanx of the middle finger of the left hand was the site of an enlargement that had increased over the period of a few months. Roentgenograms revealed a destructive process involving almost the entire distal phalanx but not the adjacent joint (Fig. 13-A). In March 1956, the involved digit was amputated and histological studies revealed a metastatic adenocarcinoma (Fig. 13-B). The patient died in July 1956.

## DISCUSSION

The fact that the hand is generally not included in roentgenographic examinations of the skeleton may account for the small number of metastatic lesions to the hand recorded in the literature. However, physicians are becoming more aware of the existence of metastatic processes to the hand for, subsequent to 1948, twelve cases had been reported, not including the seven presented in this paper.

It is quite apparent that bronchogenic carcinoma is the most frequent metastatic invader of the hand. Often, it was the secondary deposit in the hand that first drew attention to the fact that a primary neoplasm existed in the lung. The metastatic site characteristically appears inflamed, and may be painful, swollen, heated, and discolored. In most of the cases, before the true character of the lesion was recognized, the diagnosis of a felon, an underlying osteomyelitis, or other inflammatory condition was made. This fact emphasizes the necessity of examining the tissue histologically in cases of hand lesions requiring operative treatment. Within the bones of the hand, the metastatic process has seldom been observed to invade adjacent joints, although in some cases all of the intervening bone was destroyed and occasionally the overlying soft tissues were invaded. The tubular bones of the hand were invariably the site of metastatic deposits, and the carpal bones were involved once (Case 4). In the foot, the tarsal bones are involved in the metastatic process as frequently as the tubular bones[10]. Although metastatic tumors to the foot are also rare they are encountered more frequently than those of the hand [10].

Experience has indicated that a metastatic malignancy is most often confused with a felon or osteomyelitis (Fig. 8). An acute inflammatory process in the hand is not uncommon following an open injury and subsequent infection; however, the history should reveal this. Hematogenous spread of an infection from a source elsewhere in the body to the hand can occur, but again the history should give an indication of this. In the absence of injury or infection, any osteolytic lesion involving the bones of the hand producing pain, swelling, and discoloration should be regarded with suspicion.

A tuberculous dactylitis (spina ventosa) could be confused with a metastatic problem. However, this type of tuberculosis is more common in children. It invades adjacent joints, gives rise to sequestration, and causes surprisingly little pain. There may be periosteal reaction with tuberculous dactylitis but this is more often seen in syphilitic dactylitis.

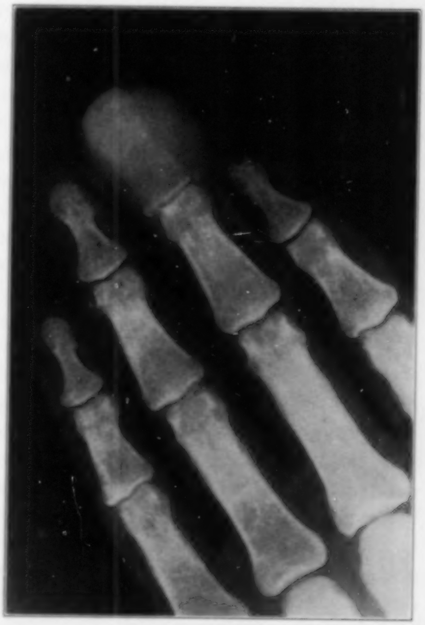

FIG. 13-A

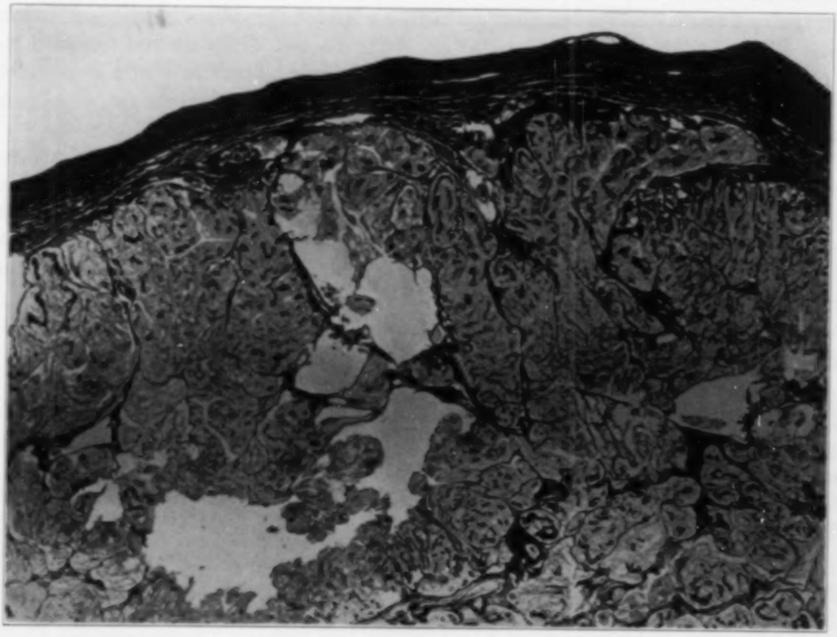

FIG. 13-B

Fig. 13-A: A destructive lesion involving the entire distal phalanx, third digit of the left hand, but sparing the adjacent joint.

Fig. 13-B: Photomicrograph (× 35) of the metastatic process illustrating the adenocarcinomatous nature of the lesion.

Enchondroma is probably the most common benign bone lesion encountered in the hand. Roentgenographically, it is characterized by an area of decreased density within the diaphysis of the bone, often expanding so that only a thin rim of cortex remains. The rounded cystlike roentgenographic appearance should not cause confusion with the irregular osteolytic process of a metastatic malignancy. Clinically, swelling of the involved area and a dull aching is typical. Not uncommonly, slight trauma produces a pathological fracture through the area of rarefaction and focuses attention upon enchondroma for the first time. It is most commonly seen between the ages of twenty and thirty years, and is most commonly located in the phalanges (Fig. 9).

At least twenty-five cases of epidermoid cyst within the skeleton of the hand have been reported, all located in the terminal phalanges [7]. This type of tumor is characterized by a smooth, well demarcated outline, but on occasion it may replace virtually the entire phalanx. In all cases a history of trauma was elicited, and the lesion was located in a terminal phalanx. An epidermoid cyst is more likely to be confused with enchondroma rather than with a metastatic tumor (Fig. 10).

Osteoid osteomata have been reported in the hand, and at least twenty-eight cases of this entity are on record. Clinically, pain, especially at night, is the most common complaint, and often aspirin will provide relief. Slow but progressive swelling of the involved bone is the rule. The roentgenograms are usually distinctive enough to differentiate this lesion by its sclerosis of the involved bone. The central nidus may appear within the medullary cavity, in the cortex, or rarely, within the periosteum (Fig. 11). Approximately 25 per cent have occurred in the carpal bones [8].

A giant-cell tumor of the hand is a slowly growing lesion which can attain considerable size before becoming symptomatic. Roentgenograms reveal a round or oval area of decreased density with a thinned but often intact cortex containing numerous fine trabeculations (Fig. 12). The possibility of malignant changes must be kept in mind when treating these tumors, but their roentgenographic appearance is sufficiently characteristic to differentiate them from metastatic bone disease. There are few recorded cases.

A simple bone cyst is a unilocular lesion that might be confused with enchondroma or giant-cell tumor but not with a metastatic deposit. Jaffe and Lichtenstein, and Carroll [7] do not believe that a bone cyst has been encountered in the hand.

Primary malignant tumors of the osseous tissue of the hand are extremely rare but osteogenic sarcomata have been reported. Pain and swelling with rapid progression is usual and roentgenograms reveal an osteolytic and osteoblastic lesion. The laying down of new bone should roentgenographically serve to differentiate this from a lytic metastasis. It has been suggested that these neoplasms may represent a malignant change from a simple chondroma [10]. Endotheliomata (Ewing's sarcoma) have been reported in the hand, but less commonly, whereas in the foot this tumor is almost as frequent as osteogenic sarcoma. In his review of hand tumors, Coley did not find fibrosarcoma.

The problem of therapy in these cases is essentially the same as that facing us in any metastatic malignant growth. Any measures that may be used to retard the primary neoplastic growth and the metastatic growth are indicated. For the most part therapy is arranged on a symptomatic and empirical basis.

In some cases, after an incision and drainage procedure has been performed on a hand with a metastatic tumor, a foul-smelling wound has ensued followed by secondary infection. In these cases, amputation of the involved digits may be indicated but only to relieve the patient of a painful and useless digit.

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## DISCUSSION

DR. ROBERT E. CARROLL, NEW YORK, N. Y.: Two of the cases presented are familiar to me. While metastatic tumors are rarely found in the hand, they should be included in a differential diagnosis. The importance of a finger lesion as the prodromal signal of organ disease cannot be underestimated.

The initial clinical appearance of this tumor frequently simulates a finger infection. A roentgenogram will be of great help in such an instance since it shows the extent and type of bone involvement. If the finger is drained, some tissue should be examined by a pathologist. In the event that the pathologist makes a diagnosis of metastatic tumor, it is my experience that amputation of the phalanx, ray, or, rarely, the entire hand, is the best method of treating the problem. There are some instances when roentgen-irradiation therapy may be of value. Metastases from a primary breast tumor are frequently radiosensitive. But, by and large, amputation is a better method and this is especially helpful in treating a metastasis from the lung.

A roentgenogram of the involved hand will help. As Dr. Kerin points out, the destructive process rarely crosses the joint space to involve the adjacent bone. The probability of an infection or a benign tumor will continue to be the most common finding in a film of the hand. In an enchondroma of the hand skeleton swelling of the involved area and a dull aching are not typical. Eighty-five per cent are found as a result of relatively minor trauma with a resulting fracture. In 10 per cent of the patients with this tumor, the enchondroma is an incidental finding when a roentgenogram of the hand is made for other purposes. In only 5 per cent does local swelling or pain produce evidence of the presence of an enchondroma in my experience.

Dr. J. Edward Flynn, Boston, Massachusetts: It would seem that because metastatic tumors of the hand are so rare that any case should be documented. In the past ten years we have one case on record. The patient, a white male, fifty-eight years old, entered the hospital with pain across both shoulders, cough, dyspnoea on exertion, and blood-streaked sputum. The primary complaint was referable to the lung. On physical examination, there was a hard, one-centimeter node just above the clavicle. On examination of the lungs, there was diminished breath sound over the left anterior wall. Cytological study revealed cancer of the lung. In the course of his hospital stay, four weeks after admission, there was pain and swelling of the left thumb. The distal phalanx was swollen and distinctly red. A roentgenogram showed a sclerotic osteolytic lesion of the distal phalanx. Histological section revealed an epidermoid carcinoma, Group II. Amputation through the metacarpophalangeal joint was performed. The microscopic section showed a crowded mass of well differentiated tumor cells, with an accumulation of carcinoma cells, fibrosis of the stroma, and occasional osteoclastic cells like giant cells.

The patient died two months after admission and autopsy revealed carcinoma with metastases.

Dr. Joseph L. Posch, Detroit, Michigan: Dr. Kerin has presented summaries of twenty-three cases of metastatic malignant tumors of the hand encountered in the literature and reported seven cases of his own.

At first, I thought it would be quite easy to find some cases in Detroit and present them here today. However, in checking the record rooms of two of our larger hospitals, I found no instances of metastatic malignant tumors to the bones of the hand. Dr. O. A. Brines and Dr. Tomiharu Hiratzka of the Department of Pathology at Wayne State University could recall no instances of metastases to the skeletal system of the hand. Dr. Hiratzka stated he had recently seen a lesion which metastasized to the biceps muscle. He felt that metastases to the skin were quite common but to the bone very rare.

It is felt that these lesions are blood-borne and that the most common offenders are primary carcinoma in the lung, breast, adrenal glands, kidney, and prostate gland.

Any lesion about the hand should be carefully examined and a section removed for microscopic examination. Although one often hesitates to operate on patients who present symptoms of pain in the hand, when the decision is finally made, a serious lesion is often encountered. A few examples that I can recall are glomus tumors, thrombosis of the superficial volar arch, tuberculous tenosynovitis, or foreign bodies.

In the past two years, we have had approximately 300 tumors of the hand. Only ten of these involved the skeletal structure and none of these were metastatic.

The very disturbing factor in this paper is that usually it was the metastatic lesion that was first encountered and frequently a primary source could not be found. It is rare that only one metastasis may occur following a carcinoma. I do, however, recall one patient with lung sarcoma and metastasis to the femur. After removal of the lung and amputation of the entire lower extremity, the patient was well thirteen years after the onset of the lesion.

It appears that those of us interested in surgery of the hand not only have to worry about the opposite cerebral cortex as Bunnell mentioned so often, but about the opposite lung as well.

# Extra-Osseous Localized Non-Neoplastic Bone and Cartilage Formation (So-Called Myositis Ossificans)

## Clinical and Pathological Confusion with Malignant Neoplasms *

BY LAUREN V. ACKERMAN, M.D., ST. LOUIS, MISSOURI

*From the Barnard Free Skin and Cancer Hospital, Barnes Hospital, and Washington University School of Medicine, St. Louis*

### INTRODUCTION

Myositis ossificans is a poor name for a group of lesions appearing in the soft tissue that may or may not be associated with periosteum. It is a poor designation established by custom; there is no inflammation, often no bone, and in some instances muscle is not included in the pathological process. During the past few years we have collected some twenty-six cases that have often raised questions of the possibility of their being neoplasms. These twenty-six were collected over a long period of time. For the most part they were referred to me for consultation (eighteen of twenty-six cases) because there was some question of sarcoma. In this group were instances of typical myositis ossificans, but there was a special group of extra-osseous lesions referred to me with the question of amputation or classification as to the exact type of sarcoma. In the treatment of this group hemipelvectomy, thigh amputation, and shoulder-girdle amputation had been contemplated procedures. It is granted that the lesions to be reported herein are rare, but the recognition that they are benign is imperative in order to avoid mutilating surgery. Progressive myositis ossificans involving many areas, a metabolic disorder occurring in children[7], and those cases of bone formation occurring following fracture, dislocation, operative procedure, or poliomyelitis[4] are not included in this discussion.

### SO-CALLED MYOSITIS OSSIFICANS

The localized lesion, classic myositis ossificans, reported by many authors, occurs particularly in young and vigorous male adults participating in sports such as football[2]. Strauss[9] reported 127 cases of traumatic myositis ossificans (cited by Lewis without reference on page 1282): "Strauss' statistics dealing with 127 cases of traumatic myositis ossificans show the following anatomic distribution: sixty-four of these occurred in the flexor muscles of the upper arm, the brachialis anticus being the one most frequently affected; forty-three occurred in the quadriceps femoris; thirteen in the adductor muscles of the thigh; two in the gluteal muscles; one in the muscles of the ball of the thumb, and one in the temporal muscle."

Geschickter and Maseritz reported on twenty-five patients with circumscribed myositis ossificans. Fifteen gave a history of injury. Twenty-one were males. The thigh was involved in fourteen instances, the arm in three, elbow in two, neck and lumbar muscles in one each. The earliest physical findings were those of a doughy mass present within a few hours of the injury. The first evidence of ossification was a small, dense shadow in the soft tissue some distance from the bone. Bone could be seen as early as three to four weeks. One of these author's recent cases showed calcification in nineteen days. This bone lesion was often surrounded by a gelatinous substance within which there was a fibrous capsule. Cystic changes were occasionally found. Degeneration of muscle, hyperplasia of connective tissue, and organization of hemorrhage were early findings. Cartilage was seen at times. The classic example of this lesion is not difficult to evaluate provided there is a good history, a characteristic location, and characteristic roentgenographic appearance. A typical example follows:

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* The data on a number of the cases cited in this paper were supplied by Dr. J. G. Weinbaum, Terre Haute, Indiana; Dr. J. Owen Blache, St. Louis, Missouri; Dr. Hollis Allen and Dr. William L. Tomlinson, St. Louis, Missouri; Dr. Franz Leidler, Houston, Texas; Dr. Max W. Rudicel, Kokomo, Indiana; Dr. H. R. McCarroll, St. Louis, Missouri; Lt. Col. Roberto E. Benitez, U.S.M.C., Frankfurt, Germany; Dr. H. D. Palmer, Denver, Colorado; Dr. Robert Fienberg, Beverly, Massachusetts; Dr. W. Harold Civin, Honolulu, Hawaii; and Dr. Jack M. Burnett, Veterans Administration Hospital, St. Louis, Missouri.

Case 25. A boy, fifteen years old, was struck in the thigh while playing. The site of injury was somewhat swollen one week later. A roentgenogram made at about the fifth week (Fig. 1-A) showed the characteristic dotted-veil appearance in which there was a shadow close to the bone within which there was evidence of new bone which seemed to have been laid down parallel to the shaft. The clinical history and roentgenograms were so characteristic in this patient that biopsy was not done and no treatment was given. Two years later the boy was well and a roentgenogram made at that time showed a localized elevation which appeared to be mainly periosteal and subperiosteal bone (Fig. 1-B).

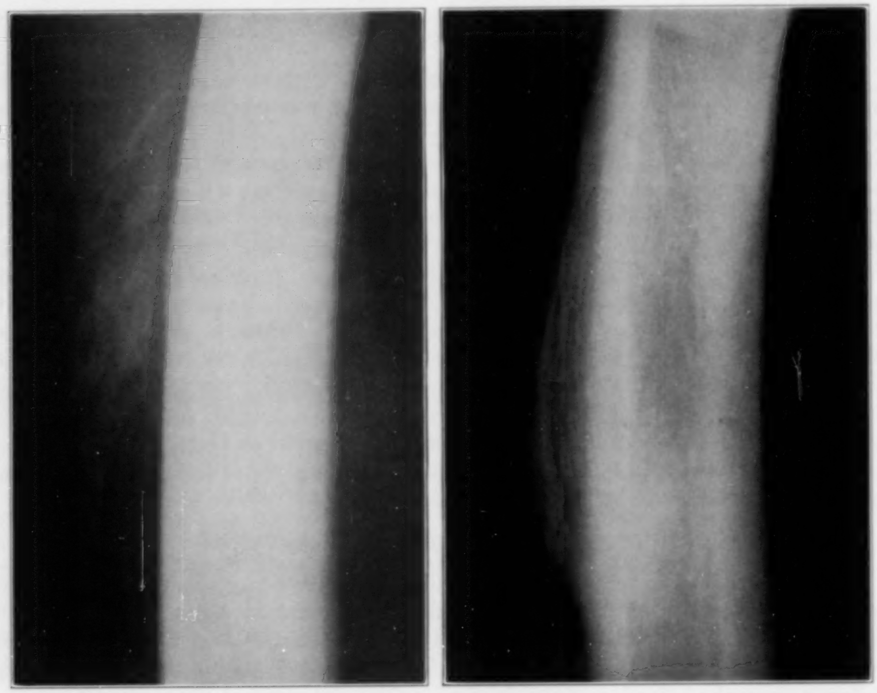

Fig. 1-A

Fig. 1-B

Fig. 1-A: Case 25. Roentgenogram made at the fifth week of myositis ossificans in a child showed characteristic dotted-veil effect (W.U. Ill. No. 56-50).

Fig. 1-B: Roentgenogram made twenty-four months later showed disappearance of the soft-tissue lesion and an area of periosteal thickening. The overlying cortex does not appear remarkable (W.U. Ill. No. 57-325).

Calcification is not present in the beginning but occurs later in the process after the formation of the osteoid. The osteoid finally develops into well oriented bone. As Constance pointed out, increasing amounts of alkaline phosphatase are produced during the evolution of the process but are not a primary cause of the changes. If biopsies are done at the time when the pathological changes are as clearly seen as in Figure 1-A, there will invariably be present well oriented bone. The second roentgenogram (Fig. 1-B) demonstrates that in this case periosteum participated in the process. Roentgenographic evidence of calcification has been seen within one month of the injury. If calcification is not present the injury occurred less than two months and probably less than four to six weeks

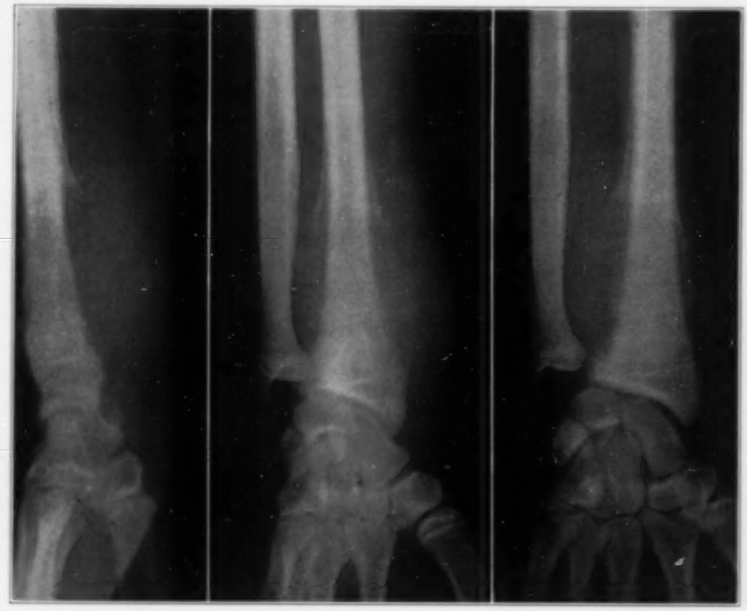

FIG. 2-A

Case 16. Prominent periosteal-bone proliferation with soft-tissue mass thought to represent possible sarcoma (W.U. Ill. No. 52-3415).

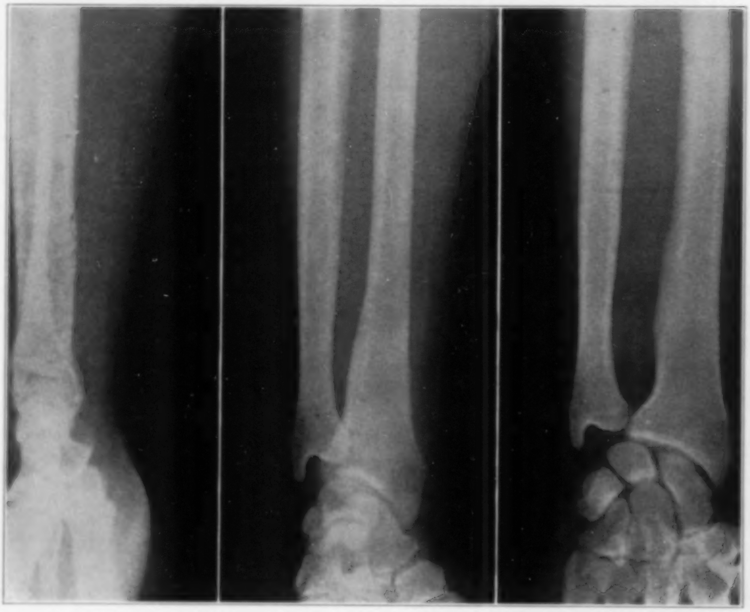

FIG. 2-B

Roentgenograms made twenty-eight months later showed complete disappearance of the process without treatment (W.U. Ill. No. 57-123).

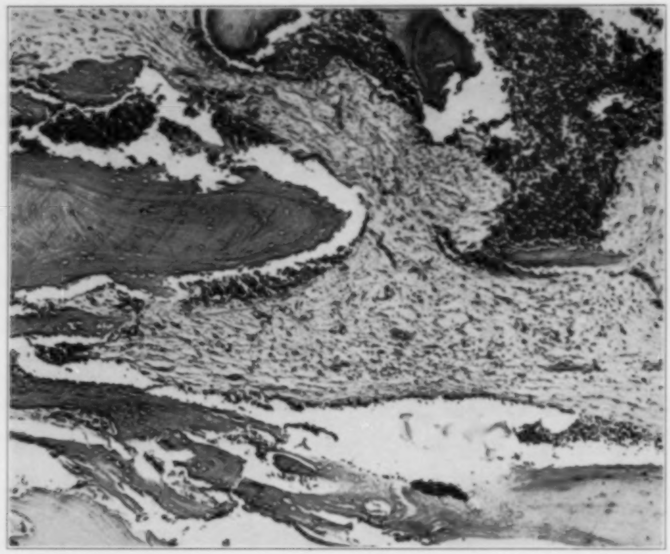

FIG. 3

Case 16. Subperiosteal hemorrhage without evidence of neoplasm (× 87; W.U. Ill. No. 52–4534).

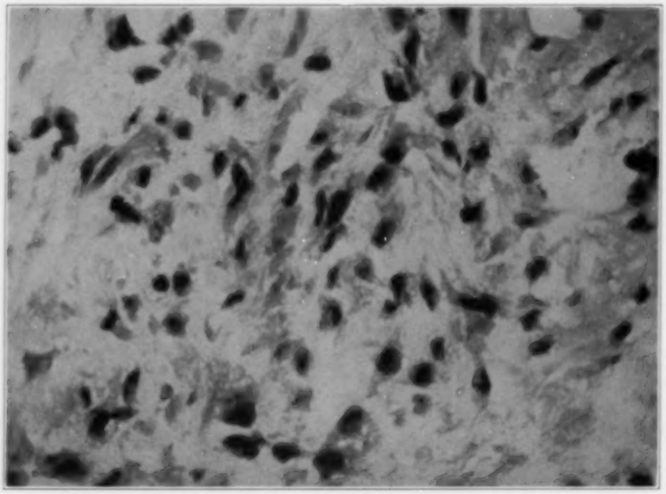

FIG. 4

Case 3. Rather cellular lesion with considerable intercellular substance and no mitotic figures (× 375; W.U. Ill. No. 55–6988).

before. In this case, typical myositis ossificans occurred in a vigorous adolescent with a history of trauma, with a typical roentgenogram in a characteristic location. These lesions are most common around the knee in the quadriceps femoris and in the anterior third of the arm involving the brachialis. It is significant that these muscles take origin from a plane surface contiguous to the bone over a wide area. It seems certain, therefore, that the periosteum participates to some extent in the process.

TABLE I

LARGE, ATYPICAL MYOSITIS OSSIFICANS

| Case | Age | Sex | History of Injury | Location | Duration | First Diagnosis | Size (*Centimeters*) | Follow-up |
|---|---|---|---|---|---|---|---|---|
| 15 | 24 | M | None | Buttock | 1 month | Osteosarcoma | 7 by 5 | Well for 21 months |
| 2 | 39 | F | None | Buttock | Unknown | Osteosarcoma | 7 by 5 | Well for 2 years |
| 7 | 27 | M | Severe, 1951 | Buttock | Unknown; noted for ten days | Osteosarcoma | 2.5 by 2 by 1 | Well for 30 months |
| 11 | 50 | F | None | Buttock | Unknown | Osteosarcoma | 4 by 2 by 2 | Well for 5 years |
| 22 | 32 | F | None | Upper arm | Unknown | Osteosarcoma | Large | Well for 15 months |

## LESIONS OBVIOUSLY ASSOCIATED WITH PERIOSTEUM

Lesions associated with the periosteum have often been reported as myositis ossificans. In the past, periosteal-bone proliferation was considered as evidence of a malignant neoplasm. It is well known to pathologists and roentgenologists that periosteal-bone proliferation is merely a manifestation of some underlying pathological process. Such periosteal-bone proliferation can be caused by infection, chronic osteomyelitis, syphilis, trauma, subperiosteal hemorrhage, eosinophilic granuloma, leukaemia, and primary and metastatic malignant tumors. It is often present in neuroblastoma, the sclerosing type of osteosarcoma, and in reticulum-cell sarcoma. In some of these conditions, the clinical history and roentgenographic findings are sufficient to make a probable diagnosis. However, in practically all instances adequate, well planned biopsies should be done. Certainly amputation should never be carried out for a lesion of a long bone without preliminary biopsy no matter how convincing the roentgenographic changes may seem to be. The following case is instructive:

CASE 16. A fifteen-year-old white male was admitted to the hospital complaining of a soft, tender mass on the wrist. The patient had been run over by a sled two months prior to admission and this injury was followed by pain. Five weeks prior to admission a small nodule was noted on the volar surface of the radius. This greatly increased in size until the time of admission. Roentgenograms were made and these showed a soft-tissue mass associated with considerable periosteal-bone proliferation (Fig. 2-A).

The roentgenograms were examined by several hundred roentgenologists and with very few exceptions the changes were felt to represent a malignant bone tumor, either osteosarcoma or Ewing's sarcoma [1]. The orthopaedic surgeons who examined the films felt similarly about the diagnosis. However, two biopsies were done and studies of the specimen revealed hemorrhage in the subperiosteal area (Fig. 3). Further investigation showed that the patient was suffering from an obscure blood disease. This blood dyscrasia together with trauma was sufficient to indicate the cause of the mass. The patient was, therefore, not operated upon and a roentgenogram made two years later revealed only slight thickening of the cortical bone (Fig. 2-B). Biopsy saved this patient needless surgery. He was well four years later. The pathological diagnosis, of course, was not difficult.

Another patient with changes in the subperiosteal areas I now believe was mishandled:

CASE 3. In June 1953, a woman, thirty-nine years old, had a small mass excised from the region of the fifth metacarpophalangeal joint of the left hand. The operation was done in another hospital where the lesion was thought to be a ganglion. The tissue had been discarded. The wound healed well but a mass developed at the site of operation in the soft tissues. Six months later the mass was excised and was considered to be benign (Fig. 4). About three weeks later the mass again recurred and at that time appeared to be highly cellular and to contain occasional mitotic figures without osteoid formation. It was thought possibly to be a fibrosarcoma (Fig. 5). Amputation was advised and the fourth and fifth fingers along with the fifth metacarpal were amputated. Sections of the specimen showed that the process was confined rather well

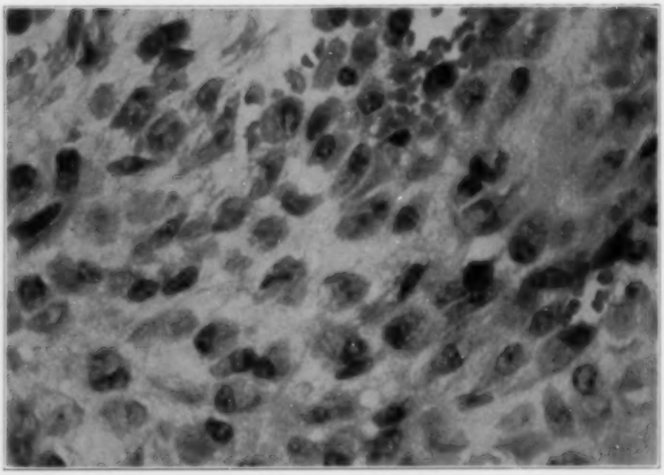

FIG. 5

Case 3. Areas considered to be malignant showing highly cellular zone, variation of size and shape of cells compatible with sarcoma. Lesion excised six months later (× 463; W.U. Ill. No. 55-6989).

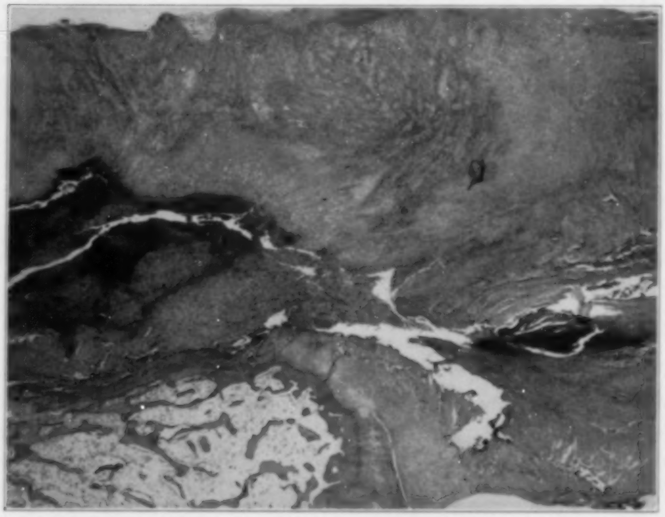

FIG. 6

Case 3. Surgical specimen showing process rather well confined to the periosteal area. Note prominent area of hemorrhage (low power; W.U. Ill. No. 55-6995).

to the periosteum and to the soft tissue surrounding it (Fig. 6). There was an area of hemorrhage present (Fig. 7), and leading away from this was fibroblastic proliferation and at the periphery was well oriented bone (Fig. 8).

A review of the last biopsy specimen showed well oriented bone in one small area. This could have led to the correct diagnosis. This patient presented an extremely difficult diagnostic problem because we never obtained a history of trauma. This case is similar to one reported by Mallory in a female, twenty-eight years old, in whom tenderness developed over the right hypothenar eminence with swelling of the palm. The hypothenar

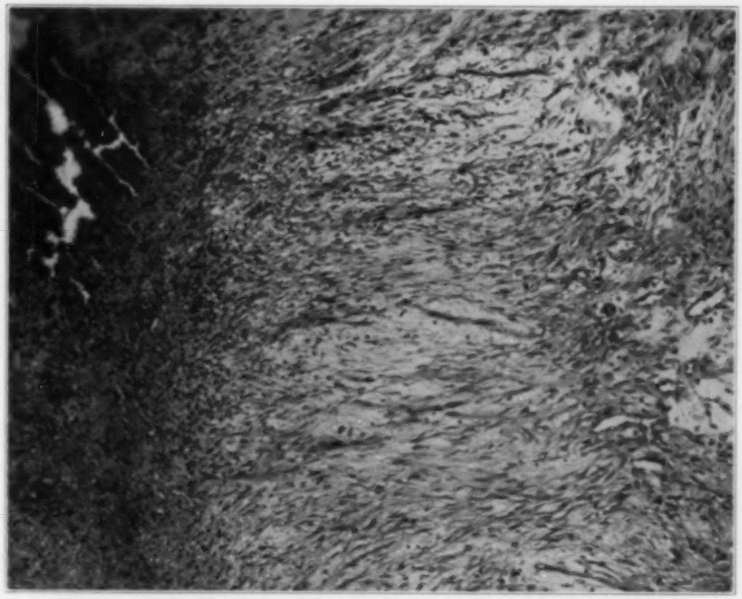

FIG. 7

Case 3. This section reveals areas of hemorrhage surrounded by fibroblastic proliferation (× 85; W.U. Ill. No. 55-6991).

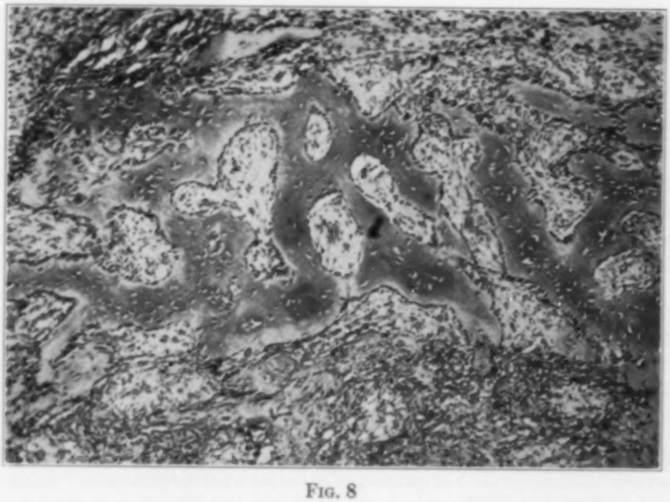

FIG. 8

Case 3. The periphery of the specimen demonstrates well oriented bone. The stroma is loose and vascular (× 57; W.U. Ill. No. 55-6993).

region was incised and firm tumor tissue was found which, on frozen section, suggested sarcoma. Several pathologists who reviewed the sections in this case thought that the tumor was osteosarcoma. In this case, successive roentgenograms demonstrated the absence of deposits of calcium until after a lamellar framework of osteoid had been laid down. Well differentiated non-calcified osteoid was demonstrated in one of the sections. Six weeks after operation there was a sharply circumscribed, densely calcified mass present and one and one-half years later there had been no change.

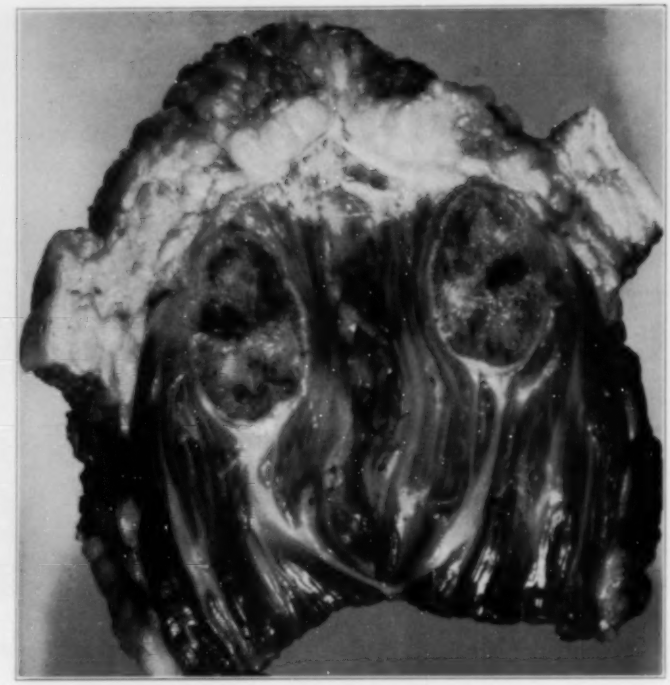

FIG. 9

Case 15. Gross specimen showing excellent delimitation of lesion within the substance of the muscle (Veterans Administration).

### LARGE LESIONS IN ATYPICAL LOCATIONS THOUGHT TO BE SARCOMA

I am not mainly concerned here with lesions of the periosteum that are usually not too difficult of interpretation, the history and roentgenograms being available. The purpose of this paper is rather to report a group of lesions much more difficult of interpretation, occurring as large tumor-like masses in atypical locations, which had been diagnosed as sarcoma and for each of which a radical surgical procedure had been recommended, such as hemipelvectomy or shoulder-girdle amputation.

The clinical histories of these patients follow:

CASE 11. A woman aged fifty had discovered a mass in her buttock. The lesion was circumscribed apparently in the belly of the glutaeus maximus and measured four by two by two centimeters. It extended into the surrounding muscle and had been incompletely removed; the treatment, in reality, being a biopsy. The patient was completely well over five years after removal.

CASE 2. A woman, aged thirty-nine, had had a baby previous to hospitalization on October 13, 1955. Two months previous to admission she had complained of having a painful sensation of sitting on a golf ball. There was a poorly defined, firm, tender mass in the left gluteal fold. This mass as seen by roentgenogram was partially calcified and measured about seven by five centimeters. The mass was removed easily by dissection. It apparently arose from the semitendinosus muscle and was attached to the ischial tuberosity; the bone was uninvolved.

CASE 15. A man, twenty-four years old, had had pain, swelling, and tenderness in the left buttock for one month. At operation a circumscribed mass about seven centimeters in diameter was found beneath the glutaeus maximus. It was not followed to its deep attachment. It was easily removed (Fig. 9). Roentgenographic examination showed calcification about its periphery (Fig. 10).

CASE 7. A man, twenty-seven years old, had noticed a tender swelling in the left buttock ten days before admission. He had been a paratrooper and, in June 1951, had sustained a bruising injury to his left hip. At

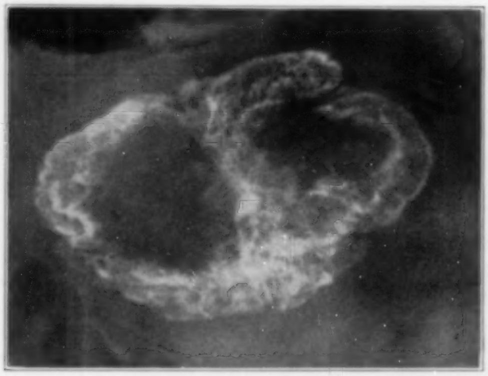

FIG. 10

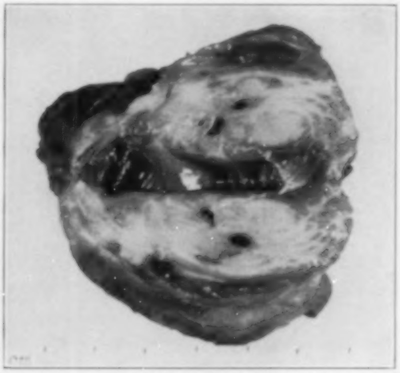

FIG. 11

Fig. 10: Case 15. Roentgenogram of specimen shown in Fig. 9 shows sharp demarcation of the lesion (W.U. Ill. No. 56-6190).

Fig. 11. Case 22. Gross photograph of well delimited, non-neoplastic lesion within the muscle (W.U. Ill. No. 56-3627).

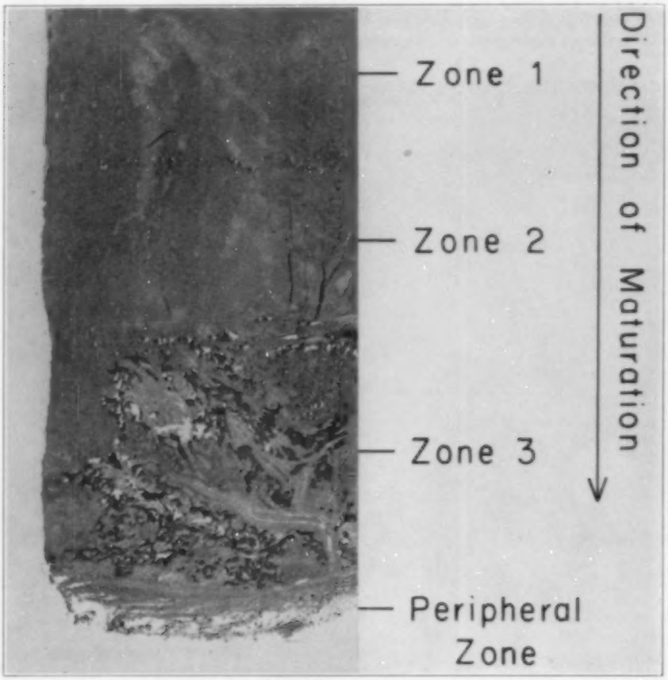

FIG. 12

Case 5. Low-power photomicrograph to demonstrate encapsulation and different pattern of the zones from the innermost cellular to the outermost zone showing well delimited bone (W.U. Ill. No. 57-1317).

operation a tumor was found in the region of the left acetabulum which one surgeon thought was attached to bone, but another surgeon did not. The tumor measured 2.5 by two by one centimeters and the cut surface was solid, white, moist, and glistening.

CASE 22. A white woman thirty-two years old noted a mass on the lateral surface of the upper part of the right arm on February 26, 1956. Two days later because of continued growth the mass was excised. It was large, well defined and not attached to bone (Fig. 11).

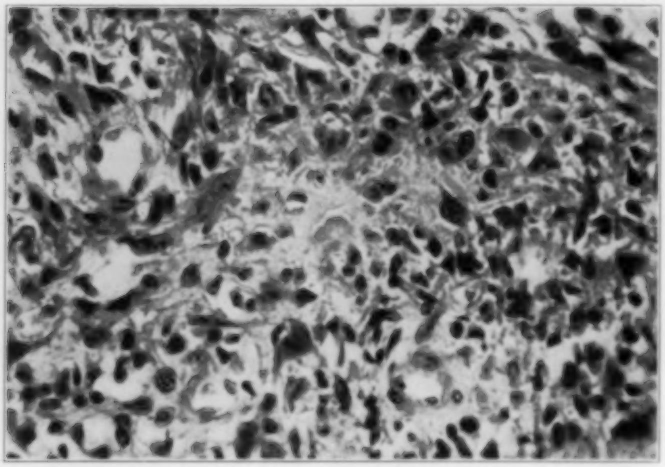

FIG. 13

Case 5. The inner highly cellular zone of the lesion shown in Fig. 12. This area with its extreme variation in size and shape of cells and mitotic activity is impossible to distinguish from sarcoma (× 287; W. U. Ill. No. 55-6881).

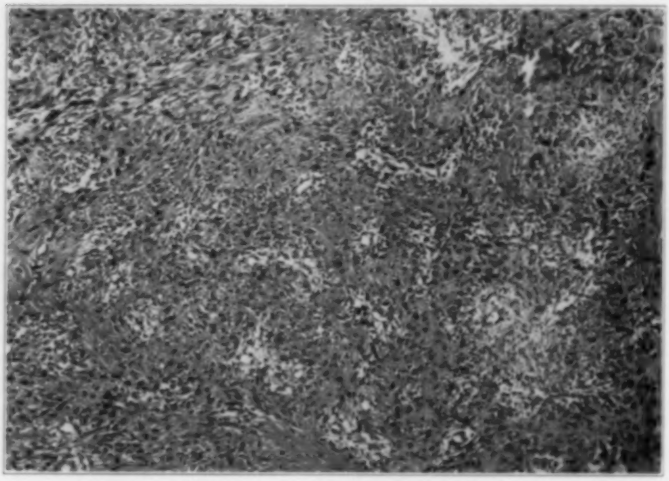

FIG. 14

Case 5. There are rather well oriented zones of cellular osteoid separated by loose cellular stroma (× 80; W.U. Ill. No. 55-6880).

In these five lesions, four were located in the buttocks and the fifth in the soft tissue of the arm. The processes were well established and formed firm, large masses. Underlying bone was not involved. All five cases showed extremely cellular areas in their central portions but if one looked at sections taken from the periphery, well delimited bone was apparent and this bone showed a stroma which was not remarkable. All of these lesions were treated conservatively. All five patients, followed for fifteen months to five years, are thus far doing well. The microscopic evaluation of these lesions would be impossible if tissue were taken from the central area or, as Johnson has indicated, if biopsy were done during the first three to four weeks when there had not yet been time for orientation or new-bone formation to occur in the periphery[8].

The recognition of these lesions is extremely difficult. However, I have been im-

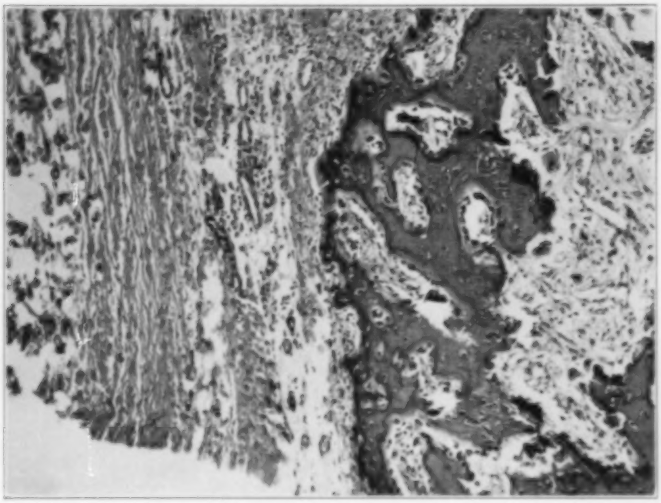

FIG. 15

Case 5. Well oriented bone on the periphery of the same lesion (× 82; W.U. Ill. No. 55-6879).

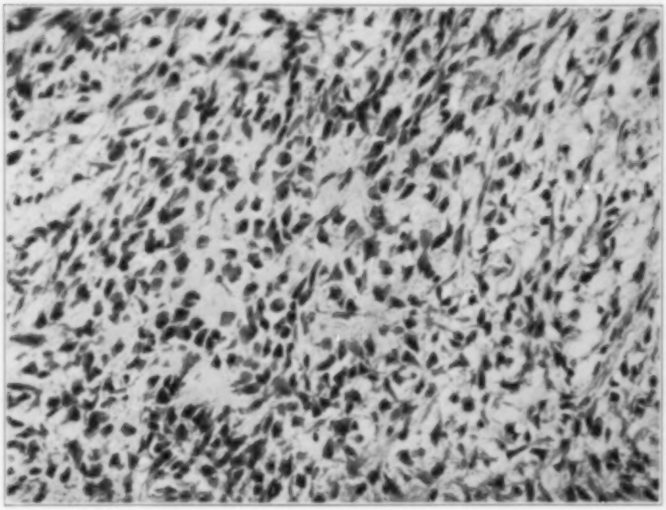

FIG. 16

Case 23. Highly cellular zone strongly suggesting sarcoma with incipient formation of osteoid. This lesion of the abdominal wall in a child was not treated and completely regressed (× 184; W.U. Ill. No. 57-06).

pressed by what I have designated as zone phenomena (inner, middle, and outer zones). Zone phenomena allow us to recognize the process as benign; they are well demonstrated in examples of classic myositis ossificans, but no one has mentioned it, probably because the process is often recognized by typical histories and location. Furthermore, if the process has progressed, well formed bone is present throughout the lesion. It has been pointed out by Dr. Lent Johnson that if such a lesion is not removed, there will be progressive orientation and maturation of the bone with the formation of a cartilaginous cap. Thus, when the tumor is removed several years after the original trauma, it will appear grossly and microscopically as an osteochondroma[8]. Such a lesion has been called a post-

TABLE II

| Patient No. and Surg. Pathol. No. | Age | Sex | Location | History of Trauma | Duration of Symptoms | Operative Findings |
|---|---|---|---|---|---|---|
| 1.<br>55–7962 | 35 | M | Soft tissue, volar surface left forearm | None | 4 months; no pain | Lesion lying between muscle fibers of brachial radialis and tumor was shelled out from within its body |
| 2.<br>55–6116 | 39 | F | Soft tissue, buttock | None | 2 months | Well defined mass without involvement of bone; appeared to be arising from semi tendinosus muscle |
| 3.<br>55–2<br>55–545<br>55–714 | 39 | F | Soft tissue, 5th metacarpal phalangeal joint right hand | None | 9 months prior to amputation | Firm mass thought to be tumor |
| 4.<br>O.S.<br>12320 | 30 | M | Soft tissue, abdomen | Stab wound | 7 weeks | Poorly defined mass of bone; size not known |
| 5.<br>53–100 | 10 | F | Soft tissue right femur at lateral epicondyle in substance of tensor fasciae latae | Followed vigorous calisthenics | 1 month | Tumor mass 3 cm. in diameter dissected off attachments of tensor fasciae latae and underlying muscle |
| 6.<br>50–3825 | 52 | M | Soft tissue overlying terminal third right femur | Hit by truck | 6 months | Large, irregular shaped calcified mass attached to lateral aspect of right femur beginning just above the condyle and extending along the shaft approximately 5 inches |
| 7.<br>55–4847 | 27 | M | Soft tissue, buttock | Telephone lineman using heavy leather support at work | 10 days | Firm tumor mass found in region of left acetabulum attached to periosteum |
| 8.<br>52–1058<br>56–153 | 32 | F | Soft tissue, buttock | None | Unknown | 1st operation: encapsulated mass between muscle, not related to periosteum; 2nd operation: well localized lesion with apparent encapsulation |
| 9.<br>54–144 | 12 | M | Soft tissue overlying ilium just beneath anterior superior spine | Possibly playing basketball | 1 week(?) | Poorly demarcated mass projecting over ilium and extending towards acetabulum; apparently related to cortical bone; surface glistening and covered by capsule |
| 10.<br>53–3119 | 6½ | F | Right mid-thigh within vastus lateralis muscle | None | 2 weeks | Multiple fragments of tissue removed incompletely from right vastus lateralis muscle |
| 11.<br>Hawaii<br>Seminar<br>Case 3 | 50 | F | Soft tissue, buttock | None | Unknown | Not available |

TABLE II

| Gross Description | Microscopic Description | X-rays | Follow-up | Remarks |
|---|---|---|---|---|
| Fairly well delimited 5 by 3 by 6 cm., very hard mass apparently fixed to fascia; does not invade the skin | Well defined young bone trabeculae separated by loose vascular stroma | 10/57 showed well delimited, superficial lesion | Recurred Oct. 1957; locally removed; similar pattern to first lesion | Not related to periosteum; thought to be malignant clinically; diagnosis made on frozen section |
| Firm mass about 5 cm. | See paper | Ill defined partially calcified mass; difficult to visualize | No evidence of disease after 2 years | Atypical case |
| Subperiosteal soft-tissue mass with central hemorrhage | See paper (Figs. 4, 5, 6, 7, and 8) | Soft-tissue swelling about metacarpal phalangeal joint | No evidence of disease after 3 years | |
| Not available | Well oriented bone formation | None | Not relevant | Presence of bone in a stab wound is not unusual and the time interval for bone formation is compatible |
| Firm, circumscribed mass, 3 cm. in diameter | Classic myositis ossificans (Figs. 12, 13, 14, and 15) | Showed soft-tissue mass with suggestion of calcification | Living and well without evidence of disease over 5 years | |
| Irregular mass of bone 5 by 1½ by 1 inches | Made up of well formed and oriented bone | None | Not available | Classic advanced myositis ossificans |
| 2.5 by 2 by 1 cm. firm, moist, white tumor | Atypical (see paper) | No mass; no definite areas of calcification | No evidence of recurrence 30 months later (9/10/57) | Atypical case |
| Very firm, ovoid tumor 5 cm. in diameter, grayish white in color | Extra-osseous osteosarcoma (Figs. 21 and 22) | Non-contributory | No evidence of recurrence 5 years from last operation | This is an example of true extra-osseous osteosarcoma |
| Non-specific fragments of gray tissue containing bone | Rather early myositis ossificans, histologically; well oriented bone | Non-contributory | An area of calcification appeared shortly after 1st operation; no evidence of recurrence 3½ years later | |
| None available | Typical well established myositis ossificans with 2-week time interval | None available | None | Classic myositis ossificans |
| Well defined mass 4 by 2 by 2 cm. | Typical myositis ossificans | None made | No evidence of recurrence after 5 years | Atypical location |

TABLE II (*Continued*)

| Patient No. and Surg. Pathol. No. | Age | Sex | Location | History of Trauma | Duration of Symptoms | Operative Findings |
|---|---|---|---|---|---|---|
| 12.<br>52–2403 | 10 | M | Soft tissue, buttock | Fracture 15 months previously | 15 months | A bridge of bone extending from the anterior superior spine of the ilium to the anterior proximal femur |
| 13.<br>O.S.<br>67265 | 18 | F | Soft tissue, knee | None | Unknown | Well defined mass entirely within soft tissue |
| 14.<br>50678 | 12 | F | Soft tissue upper thigh in close apposition to metaphyseal area of femur | None | Unknown | Firm mass attached to greater trochanter |
| 15.<br>V.A.<br>49–56 | 24 | M | Soft tissue, buttock | None | 1 month | Apparent circumscribed mass just beneath glutaeus maximus |
| 16.<br>52–958 | 15 | M | Soft tissue, volar surface of wrist | Run over by a sled | 2 months | An incision was made over the head of the left radius to bone and much clotted and liquid blood was aspirated; bone surface somewhat eroded |
| 17.<br>54–1019 | 21 | F | Soft tissue, neck | Stiff neck treated by traction | 5 months | Well delimited tumor found in posterior triangle |
| 18.<br>56–1121 | 51 | F | Soft tissue, deltoid area left arm | Questionable | 6 weeks | Poorly defined gray mass within muscle |
| 19.<br>55–5447 | 68 | M | Soft tissue, inner aspect thigh | None | 5 days | Enlargement middle half sartorius muscle; muscle appeared gray |
| 20.<br>56–1226 | 60 | M | Soft tissue, antecubital fossa | None | Not given | Not given |
| 21.<br>56–1471 | 16 | M | Soft tissue, right thigh | Blow to right thigh 4 months before | 5 weeks | Cystic structure 2.2 cm. covered by muscle which contained old blood |
| 22. | 32 | F | Soft tissue, upper arm | None | Not known | Not available |
| 23.<br>56–4851 | 15 | F | Soft-tissue tumor, abdominal wall; probably in close relation to fascia | Not known | Not known | Tumor 2 cm. in diameter protruding through fascia |
| 24.<br>56–2243 | 8 | F | Soft tissue, ankle | Sprained ankle several times | 2 weeks | Hard, tumor-like mass excised |
| 25. | 7 | M | Soft tissue, thigh | Struck while playing | 5 weeks | No surgery |
| 26.<br>57–289 | 48 | F | Left thigh localized in head of biceps femoris | None | 2 days | Muscle felt firm |

TABLE II (*Continued*)

| Gross Description | Microscopic Description | X-rays | Follow-up | Remarks |
|---|---|---|---|---|
| Well formed bone | Normal bone | Demonstrated the bridge of bone | None | Bone formation followed fracture |
| Well circumscribed lesion with apparent encapsulation without involvement of bone | Typical myositis ossificans | Soft-tissue calcification medial to the tibial tuberosity; no changes of bone | Amputation done on incorrect diagnosis of osteosarcoma | The central area microscopically with its bizarre pattern resulted in the incorrect diagnosis |
| Non-contributory | Typical myositis ossificans | Showed well delimited mass in close proximity to the greater trochanter | Mass progressively decreased in size over next 2-year period; patient living and well, June, 1957 | |
| Well circumscribed firm gray mass with apparent bone in periphery of mass (Fig. 9) | Typical microscopic appearance of myositis ossificans | See paper (Fig. 10) | No evidence of recurrence, September 1957 | Atypical location |
| Non-diagnostic | Subperiosteal hemorrhage with organization and bone formation (biopsy only, Fig. 3) | Periosteal-bone proliferation (Figs. 2-A and 2-B) | Complete reversal of x-rays to normal in 5 years | Lesion caused by trauma with hemorrhage; diagnosed by x-ray as malignant bone tumor |
| Mass 5½ by 3½ cm., ovoid in shape; glistening gray-blue capsule; periphery had stony hard consistency | Myositis ossificans; excellent formation of well oriented bone | Calcified mass, posterior triangle | No evidence of recurrence 3 years later | Lesion followed traction |
| 6 by 3 by 2 cm. muscle mass, gray in color with poorly defined boundaries | Death of muscle with giant cells | Non-contributory | No evidence of recurrence 18 months later | |
| 8 by 6 by 3 cm. mass; in the central portion muscle felt firmer and was pale and gray | Death of muscle with giant cells (Figs. 17 and 18) | None | No evidence of recurrence after 25 months | |
| Not given | Death of muscle with giant cells | None | No evidence of recurrence after 20 months | |
| Calcific areas in the capsule | Organizing hematoma with bone formation | Area of calcification, right thigh | No evidence of recurrence after 1 year | |
| Fairly well delimited mass firmer in periphery than in central area (Fig. 11) | Myositis ossificans in atypical location | Non-contributory; bone negative | No evidence of recurrence after 15 months | |
| Tumor 2 cm. in diameter | Showed early osteoid formation and high degree of cellularity (Fig. 16) | None | No evidence of recurrence after 15 months | |
| 25 mm. mass showed bone trabeculae | Well oriented bone formation; typical myositis ossificans | Hazy calcification between tendo achillis and ankle joint | No evidence of recurrence after 15 months | |
| No specimen | No specimen | Typical myositis ossificans (Figs. 1-A and 1-B) | Resolved completely without treatment; no evidence of recurrence after 24 months | |
| Mass 5 by 3 inches, ovoid in shape, grayish-white color | Destruction of muscle with early osteoid (Figs. 19 and 20) | Non-contributory | No evidence of recurrence after 10 months | |

traumatic osteochondroma. This sequence of events with osteoplastic resorption probably occurs because of muscle action over the lesion; this is particularly common in the region of the knee joint. Some ossifications completely disappear and probably the smaller ones regress because of osteoclastic absorption in the belly of the muscle. There is complete restoration of muscle contour but muscle function is never normal[13]. The zone phenomena are well illustrated by a classic case in a ten-year-old child.

CASE 5. A well defined lesion on the superolateral aspect of the knee joint was excised. Microscopically, with low magnification, it was seen to be well delimited with a central cellular area and a peripheral area which showed excellent bone formation (Fig. 12); with high magnification, the central zone showed extreme variation of cells and atypical mitotic figures (Fig. 13). (Such zones cannot be distinguished from sarcoma.) The next section (Fig. 14), closer to the periphery, showed an attempt at orientation with poorly defined osteoid.

These changes are suggestive because the pattern is regular and the cells between the zones of early-forming osteoid are not neoplastic. In a lesion early in its evolution, such changes may be the only ones to indicate that the process is benign. In the margins there is well formed bone covered by connective tissue (Fig. 15).

The following case is presented to describe the lesion early in its evolution:

CASE 23. A fifteen-year-old girl had a lesion of the abdominal wall. There was no history of trauma. Since the lesion was early in time, the great cellularity made evaluation difficult. However, microscopically, with low magnification, organization and orientation of the process was seen to be taking place and there was incipient osteoid formation (Fig. 16). The excellent orientation of the osteoid was the only hint microscopically that the process was benign. This is the type of change depicted in the middle zone in fairly well developed lesions. No further treatment was given and twenty-four months later the child was well. Later in time the zone phenomena would have been fully developed.

## DISCUSSION

I suspect that the pathological genesis of myositis ossificans is related to injury, that the injury causes death of muscle, and that death of muscle is followed by progressive alterations in the tissue which are microscopically distinctive. I feel that death of muscle does not necessarily result in myositis ossificans but may result in increased fibrous tissue and tumor-like proliferation. I have seen three patients in whom a diagnosis of sarcoma was considered. In one of these patients there was a history of trauma (Case 18) and in the second there was no history of trauma (Case 19). In one, the lesion was in the soft tissue of the arm (anterior deltoid region) and in this patient a mass five by three by two centimeters was removed (Case 18). In the second patient (Case 19), the mass was in the thigh and it was about the same size as that in Case 18. Both were poorly delimited and had been diagnosed by several pathologists as sarcoma. Both were incompletely excised and in both no further treatment was given. Microscopically there was death of muscle (Fig. 17) with broad areas of proliferation of connective tissue with large, atypical nuclei (Fig. 18) (Case 19). The third case (Case 26) occurred in a woman forty-eight years old. About a week prior to surgery she had noted a painful swelling of her thigh localized to the head of the biceps. The region was explored and the head of the biceps femoris showed swelling and had a speckled appearance. Microscopically, under low-power magnification, the sections showed dead and dying muscle cells (Fig. 19). Between these muscle cells and in the fibrous septa there were collections of bizarre cells. Many of these were fibroblasts but some were also muscle cells. It would be easy to call such a lesion sarcoma (Fig. 20).

In rare instances, fibrous-tissue proliferation associated with periosteum in the subperiosteal zone may be accompanied by extremely cellular proliferation difficult to evaluate. Even in such areas, zone phenomena should be watched for. However, as this paper has demonstrated by the case reports of unusual large tumors of myositis ossificans located in unusual locations, the referring pathologist is confused by the extremely cellular

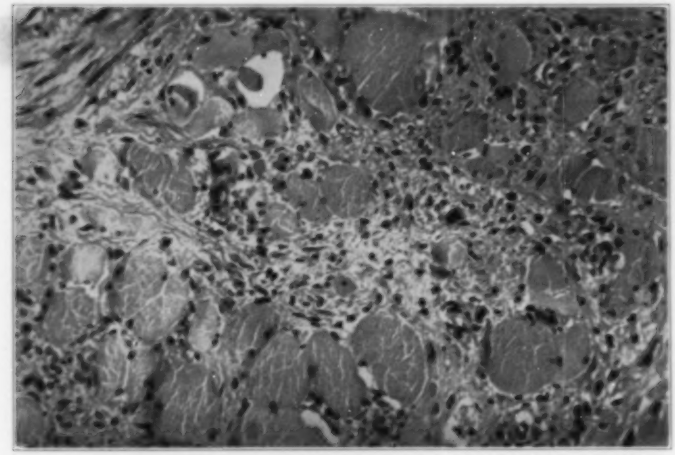

FIG. 17

Case 19. Death of muscle with proliferation of fibroblasts microscopically confused with sarcoma (× 200; W.U. Ill. No. 56-4005).

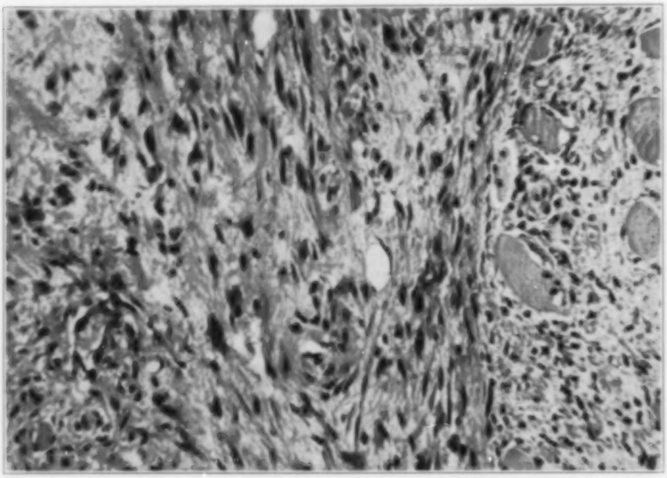

FIG. 18

Case 19. A more cellular area from same case as Fig. 17 which even more resembles sarcoma (× 250; W.U. Ill. No. 56-4007A).

picture, the unusual location at times, and, often, no history of trauma. He usually pays little attention to the maturation changes in the tissue.

Zone phenomena are not present in soft-tissue sarcomata, although there is pseudo-encapsulation. An extremely rare lesion, extra-osseous sarcoma which was so well reported by Fine and Stout, may be difficult to evaluate. Death occurs from metastases[12]. A good example of this lesion was a tumor in the buttock of a woman, thirty-two years old, in whom there was no history of trauma. A mass approximately five centimeters in diameter was removed with fragments of muscle. It recurred in August 1952 and was again removed by very wide excision. Three years after excision the patient was living without evidence of disease.

A review of the histological sections showed extreme disorganization of the tumor with many bizarre mitotic figures present throughout (Fig. 21). While osteoid was present,

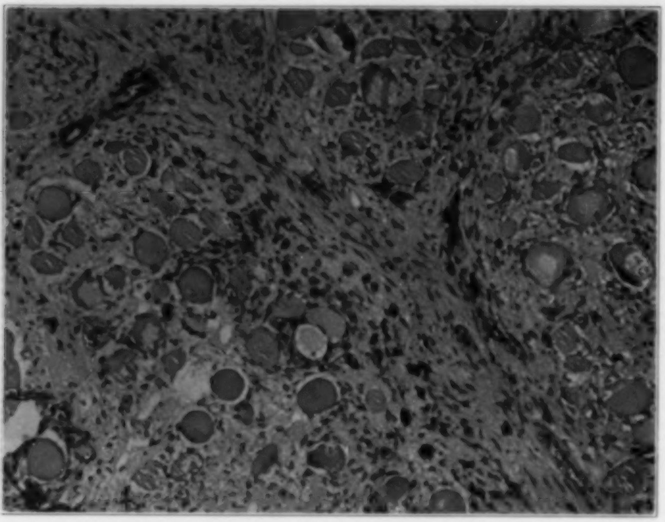

FIG. 19

Case 26. Dead and dying muscle with bizarre cellular alterations in a biopsy specimen taken from the biceps femoris muscle. The symptoms were of one week's duration (× 96; W.U. Ill. No. 57-420).

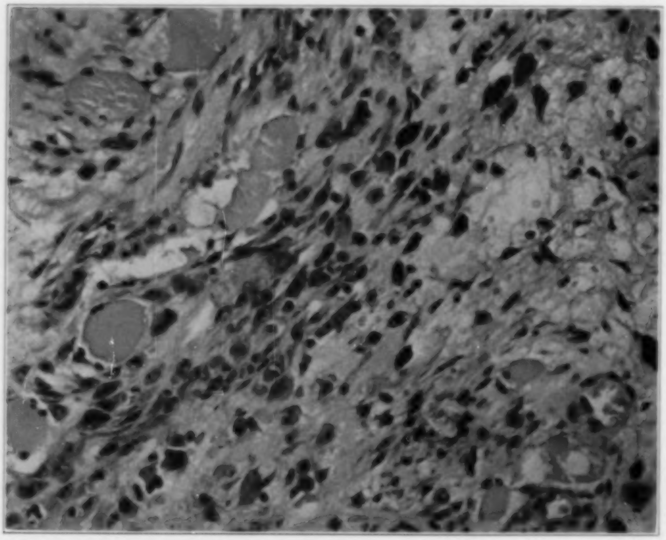

FIG. 20

Case 26. Highly cellular zone strongly suggesting sarcoma at higher magnification than Fig. 19 (× 235; W.U. Ill. No. 57-421A).

there was no true bone formation; I feel this must be classified as a true extra-osseous osteosarcoma. This lesion had a rather well delimited mass but the encapsulation was false as is so common in soft-tissue sarcomata (Fig. 22). The important microscopic diagnostic finding was the uniform presence of undifferentiated tumor throughout the entire neoplasm. In other words, there was no evidence of zone phenomena such as we find in myositis ossificans and there was no true well oriented bone present. Furthermore,

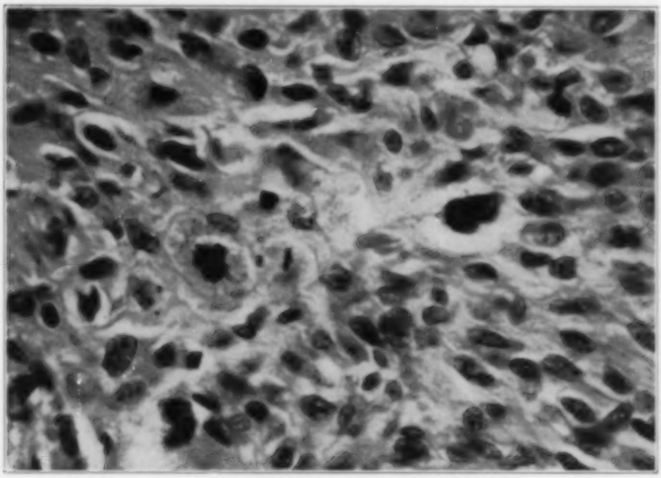

FIG. 21

Case 8. Extra-osseous osteosarcoma with bizarre mitotic figures and extreme cellularity (× 375; W.U. Ill. No. 56-212).

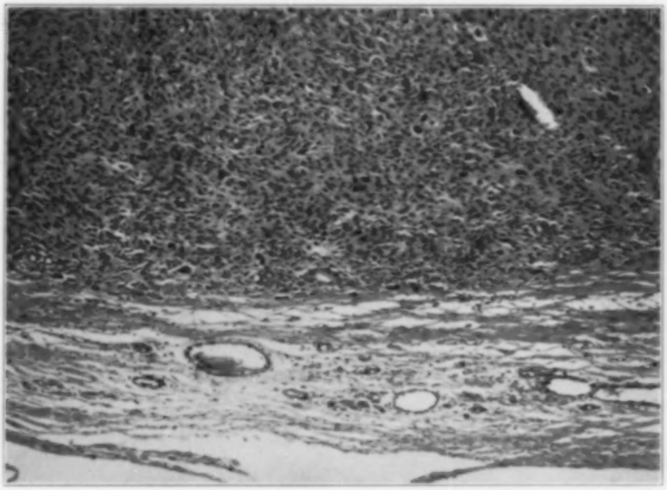

FIG. 22

Case 8. Low-power photomicrograph of extra-osseous osteosarcoma demonstrating that the malignant changes extend throughout the lesion to the periphery (× 55; W.U. Ill. No. 56-213).

there was no evidence of pre-existing myositis ossificans, and I, personally, have never seen a transition from myositis ossificans to a malignant tumor such as was once reported by Pack and Braund.

Therefore, in lesions in atypical locations forming large masses the pathologist and orthopaedic surgeon should always think of myositis ossificans. There is frequently no history of trauma; therefore, the diagnosis must be established mainly on the basis of pathological findings with emphasis on zone phenomena. In looking for the latter it is important to remember that different degrees of maturation exist with the best differentiated zone on the periphery.

## CONCLUSIONS

In taking the history in these atypical instances of myositis ossificans one should pay particular attention to previous trauma. If there is history of trauma, careful timing of the progression of the pathological process is helpful in diagnosis. Finally, and most important, in these atypical cases as well as the typical cases, zone phenomena are present. There is a central, undifferentiated zone impossible to distinguish from sarcoma. This zone merges into oriented osteoid formation and finally, into well formed bone in the periphery of the lesion. If these zones are present, they are of paramount importance in making a diagnosis of a benign process and may save the patient from mutilating and needless surgery.

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# Mobilization of the Tarsometatarsal and Intermetatarsal Joints for the Correction of Resistant Adduction of the Fore Part of the Foot in Congenital Club-Foot or Congenital Metatarsus Varus *

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The purpose of this communication is to introduce a conservative operative procedure for the correction of residual and resistant adduction deformity of the fore part of the foot in the treatment of congenital club-foot, and in the treatment of resistant cases of the deformity commonly known as congenital metatarsus varus. It is not uncommon to encounter these conditions in children three years of age or more. At this age correction is quite difficult, and becomes increasingly so as the child grows older. Repeated manipulations or wedging of plaster casts are not only ineffective in these older children, but also produce still more fibrosis and joint stiffness. Complete section of the resistant joint capsule, ligaments, or other fibrous-tissue bands which resist correction, is much more effective and causes less trauma. This procedure mobilizes the joints immediately and permits approximately normal restoration of the bone relationships and alignment of the fore part of the foot. This comparatively simple procedure was successful in correcting resistant adduction deformity in the fore part of the foot in many patients seven years of age and younger, without osteotomies, bone excisions, or wedge resections being necessary.

We are accepting the term *metatarsus varus* in this discussion because of its common usage. It is not so important, regarding the operative procedure to be described, to decide whether the term *pes adductus*, *metatarsus adductus*, *metatarsus adductovarus*, or *metatarsus varus* is more accurately descriptive of the deformity of the fore part of the foot. For studies and descriptions of the pathological anatomy of metatarsus varus, attention is called to the publications of Peabody, Kite, McCormick and Blount, Steindler, and Fliegel. One must recognize, however, that metatarsus varus with more obvious adduction of the fore part of the foot at the tarsometatarsal joint is sometimes complicated with a considerable degree of eversion of the heel at the mediotarsal joint. The deflection of the fore part of the foot, in valgus deformity of the hind part of the foot, may compensate to restore the axis of the entire foot to a reasonably good alignment. Hence, correction of only the adduction of the fore part of the foot, without attention to the deformity at the hind part of the foot, may aggravate the valgus ankle and result in a more conspicuous and disabling pes valgus. The same precaution applies to complete correction of adduction or varus deformity of the fore part of the foot in congenital club-foot in which there has been overcorrection of the deformity of the hind part of the foot.

The resemblance of the deformity of the fore part of the foot in club-foot and in metatarsus varus is so close that the same principles and methods of treatment apply to each condition. Operations for club-foot to release ligaments and fibrous-tissue bands at the medial aspect of the ankle and foot, such as Ober's and Brockman's operations, are widely known for correction of inversion of the heel, medial displacement of the navicular bone on the head of the talus, and possibly to improve upon the adduction of the first metatarsal bone. However, these procedures little improve the adduction of the entire

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* Read in part at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 24, 1957.

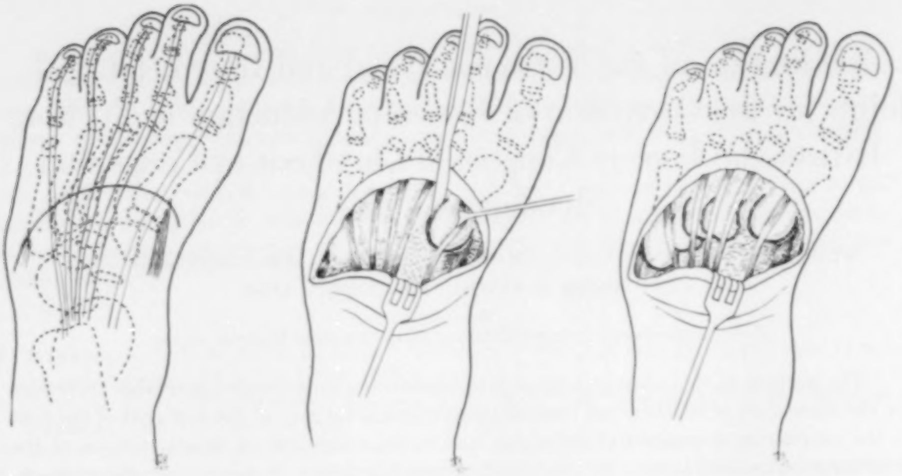

FIG. 1-A

FIG. 1-B

FIG. 1-C

Figs. 1-A to 1-E: Drawings show the steps of the operation to correct adduction deformity of the fore part of the foot. The outlines of the fore part of the foot and bones are accurate tracings of roentgenograms made of W. H. (Case 13) before operation and immediately after the cast was removed.

Fig. 1-A: Drawing shows the curved incision made across the dorsum of the foot.

Fig. 1-B: The dorsal and interosseus ligaments and joint capsule of the first tarsometatarsal joint are cut by a deep incision carried around the base of the first metatarsal, as shown in illustration. Care is taken not to cut the tibialis anterior tendon at its insertion.

Fig. 1-C: Drawing shows that, in a similar way, a deep incision is carried around the base of each of the other metatarsals, and the intermetatarsal ligaments as well as the tarsometatarsal ligaments are freely cut. Care is taken not to cut the peronaeus brevis tendon.

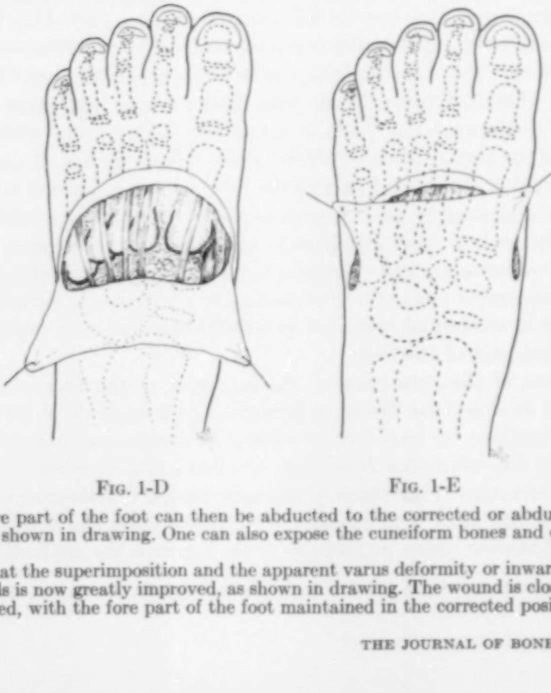

FIG. 1-D

FIG. 1-E

Fig. 1-D: The fore part of the foot can then be abducted to the corrected or abducted position without much resistance, as shown in drawing. One can also expose the cuneiform bones and cut the ligaments surrounding them.

Fig. 1-E: Note that the superimposition and the apparent varus deformity or inward twisting of the middle three metatarsals is now greatly improved, as shown in drawing. The wound is closed and a well molded plaster cast is applied, with the fore part of the foot maintained in the corrected position.

fore part of the foot in club-foot or in metatarsus varus. In these conditions, there is resistance to correction at all of the tarsometatarsal and intermetatarsal articulations.

There is not much written on the treatment of resistant adduction of the fore part of the foot in children beyond the age when it can be corrected by manipulations and casts. One cannot expect that any tendon transposition, such as the insertion of the tibialis anterior to the proximal end of the fifth metatarsal bone, will correct a fixed deformity which does not yield passively beforehand. Garceau stressed that this operation is not recommended for correction, but rather for prevention of recurrence of club-foot deformity. Nor can we expect that resistant metatarsus varus in older children will be overcome by transfer of the insertion of the tibialis anterior to the third cuneiform bone. In meeting this situation for metatarsus varus, Peabody wrote that he would advise "(1) excision, probably *en bloc* and through a central incision of the bases of the three middle metatarsals; (2) subcutaneous osteotomy of the fifth; (3) mobilization and reduction of luxation of the first metatarsocuneiform joint with appropriate attention to insertion of the tibialis anticus; (4) consequent manipulation to produce a completely abducted and pronated foot." McCormick and Blount recommended a wedge resection in the region of the cuboid in patients whose condition had been neglected, or arthrodesis of the first metatarsocuneiform joint with osteotomy of the middle three metatarsals. Steindler stated that correction of the deformity in children over three years of age is very difficult, and that open methods of wedge resections must then be resorted to. Our efforts have been directed toward less radical treatment.

At the tarsometatarsal articulations, the bases of the five metatarsal bones are firmly bound to the three cuneiform bones and to the cuboid by strong dorsal, interosseus, and plantar ligaments. The bases of the lateral four metatarsal bones articulate with each other, and are firmly bound together by strong dorsal, interosseus, and plantar ligaments. The operation submitted by the authors consists in mobilizing these joints by freely cutting the tarsometatarsal and intermetatarsal ligaments and joint capsules. This is a conservative procedure which does not injure bone or disturb bone growth. The approach is through an incision across the dorsum of the foot, which provides an excellent exposure of all of these articulations, and permits a good exposure of the cuneiform bones when cutting the ligaments of these articulations may also contribute to mobilization of the fore part of the foot. The transverse incision has regard for the creases of the skin, and has the advantage that the entire tarsometatarsal joint is seen. There were no complications in wound healing in our patients upon whom this operation was performed. For convenience, we term this operation *anterior capsulotomies*, in distinction from medial capsulotomies which refer to the release of soft-tissue structures at the medial aspect of the ankle and foot.

## OPERATIVE TECHNIQUE

With a pneumatic tourniquet in place, a curved incision is made across the dorsum of the foot, beginning at the medial side of the first tarsometatarsal joint and extending to the base of the fifth metatarsal bone. The incision may be extended proximally at the medial side to expose the cuneonavicular articulation so that these ligaments may be cut if they also appear to offer resistance to correction. The skin flaps are retracted upward and downward, exposing the deep fascia covering the tarsometatarsal articulations. The tibialis anterior tendon is identified and protected, and attention is paid to any abnormality of its insertion. During the course of the procedure which follows, care is taken not to cut the extensor tendons. In younger children, one may not readily identify the middle three tarsometatarsal joints, but with patience it is not difficult.

A longitudinal incision is made through the deep fascia over the first tarsometatarsal joint. This fascia is retracted, exposing the dorsal ligaments. The dorsal and interosseus ligaments and joint capsule are cut freely by a deep incision carried around the base of the first metatarsal, taking care not to cut the tibialis anterior tendon at its insertion. The joint is then flexed sufficiently so that the knife may be inserted through it to cut the capsule and ligaments at the plantar aspect. Although this joint is now mobilized, it is clear that this procedure alone is insufficient to attain appreciable correction of the deformity of the fore part of the foot. Another longitudinal incision is then made through the deep fascia over the interval between the bases of the second and third metatarsals. The articulations of both these bones can be exposed by retracting the deep fascia. A deep incision is made encircling the base of each of these metatarsals, and the joint capsules and the dorsal, interosseus, and intermetatarsal ligaments of these articulations are freely cut through. Similarly, a third longitudinal incision is made through the deep fascia over the interval between the bases of the fourth and fifth metatarsals and the corresponding ligaments and capsules of these articulations are cut. Finally, by exerting traction upon all metatarsals and flexing the tarsometatarsal joints, the knife is introduced through each joint to cut the capsules and ligaments transversely at the plantar aspects. One may also encircle the knife between and around the cuneiform bones, but this does not contribute much more to the mobilization of the fore part of the foot.

After the ligaments and joint capsules of the intermetatarsal and tarsometatarsal articulations are thoroughly cut through, the lateral four metatarsal bones will glide upon one another and the fore part of the foot will swing outward at the tarsometatarsal joint without much resistance. If the child is young enough, or if bone deformity has not progressed to a serious degree, the adduction deformity can be overcorrected. The skin is then closed, and a well molded plaster cast is applied with the fore part of the foot held in as much abduction as possible, with care taken that the heel is not everted.

Two weeks after the operation, the cast is changed in order that the foot may be inspected. The correction may not have been as thorough as was thought, and a little more stretching of the fore part of the foot into further abduction may be desirable. As a rule, however, this is not necessary. It is recommended that the foot be maintained in the corrected position in the plaster cast for at least three months. Weight-bearing and walking in the functional position of correction while the patient is wearing the cast are stimulants toward maintenance of correction after the cast is removed.

The case histories of the first two patients operated upon are illustrative. Except for the second patient, all patients had long histories of unsuccessful treatment by the usual conservative methods. Some patients had had no treatment until they were several months of age. Many patients had been under treatment by other physicians for from several months to two or three years before coming to us.

The first operation was done in July 1945 on J. B., a girl five and one-half years old. She had been under our treatment for congenital club-foot since she was six weeks old. Treatment had consisted in gentle manipulations and applications of plaster casts, Denis Browne splints, adhesive strappings, followed by another series of plaster casts. When the patient was two years old, there appeared to be complete correction, and treatment then consisted in passive stretchings by her mother under the supervision of an experienced and trustworthy physical therapist. One year later, when she was three years old, there was a recurrence of both the inversion and adduction components of the deformity, which were again treated by wedging of plaster casts. Continued efforts along these lines failed to correct the deformity. There was, incidentally, a congenital shortening of the first metatarsal bone, but it was not felt that this contributed to the difficulty in correction.

In November 1944, when the girl was almost four years old, an operation was performed to release the soft-tissue structures at the medial aspect of the ankle and foot. This was successful in correcting and maintaining correction of the inversion of the heel and restoring reasonably good position of the navicular bone in relation to the head of the talus, but there still remained a rather severe degree of adduction of the fore part of the foot (Fig. 2-A). It was then decided to implement the same principles of releasing the resistant ligaments and joint capsules to correct the residual adduction deformity of the fore part of the foot. After a deep incision was made completely around the proximal ends of each metatarsal, through the intermetatarsal and tarsometatarsal joints, the fore part of the foot was mobilized, and could be corrected without difficulty. A plaster cast was applied with the fore part of the foot held in moderate abduction.

When the cast was removed, ten weeks after the operation, the deformity was corrected, and roentgenograms showed improvement (Fig. 2-B). The girl had no further treatment, and there was no recurrence of deformity. Figures 2-C and 2-D show photographs and a roentgenogram made when she was seventeen years old, eleven and one-half years after the operation.

The second operation was done in August 1945 on J. T., a boy five years old, who had a severe metatarsus varus deformity of the right foot and who had never had any treatment (Fig. 3-A). Because of his age and the severity of the deformity, it was not considered worth while to try any manipulative method of treatment, but to proceed at once with anterior capsulotomies. We were again gratified by the ease of immediate mobilization and correction. Postoperative correction of the foot in the plaster cast was maintained for seven weeks. Figure 3-B shows a roentgenogram made when the cast was removed. The boy had no further treatment, and the deformity remained well corrected. Figures 3-C and 3-D show photographs and a roentgenogram made when he was sixteen years old, eleven years and four months after the operation.

The essential data concerning all patients are recorded in Table I. All operations were done by one or another of the authors; none was done by a resident in training. Every patient operated upon was examined by us during the last four months preceding the writing of this report. Except for that in E. Z. (Case 19), we have not observed any abnormality of the insertion of the tibialis anterior tendon. This child had a most severe and

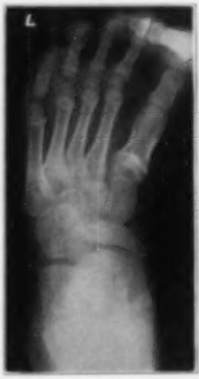

FIG. 2-A

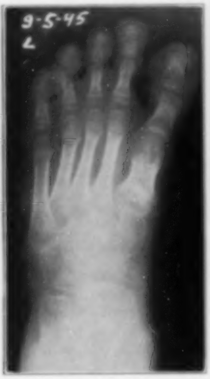

FIG. 2-B

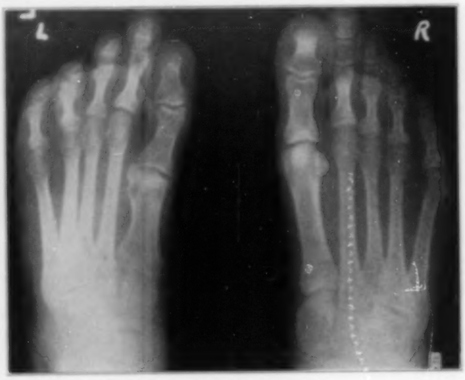

FIG. 2-C

Fig. 2-A: J. B. (Case 1). Roentgenogram made June 1, 1945, when the patient was five and one-half years old, showing residual adduction of the fore part of the left foot.

Fig. 2-B: Roentgenogram made September 5, 1945, when the cast was removed, ten weeks after anterior capsulotomies.

Fig. 2-C: Roentgenogram of both feet made January 4, 1957, eleven years and seven months after the operation.

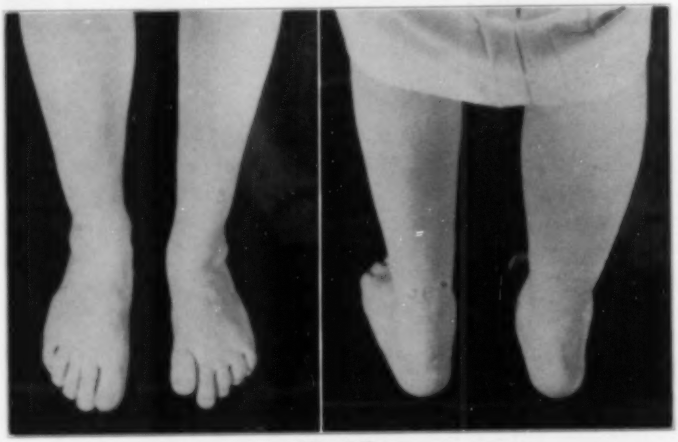

FIG. 2-D

Photographs made January 4, 1957.

almost rigid metatarsus varus of both feet accompanied by multiple congenital defects, including anterior bowing of both tibiae, congenital scoliosis, and cleft palate.

Twenty-nine operations were performed upon twenty patients, nine patients having operations on both feet. Twenty operations were done to correct residual adduction deformity of the fore part of the foot in club-foot, and nine operations were done to correct metatarsus varus. Only one patient was under three years of age. The ages of the other children ranged from three years and three months to seven years and two months. It is important to take into consideration that all children, except for J. T. (Case 2), had been under continuous or intermittent treatment by us or by some other orthopaedic

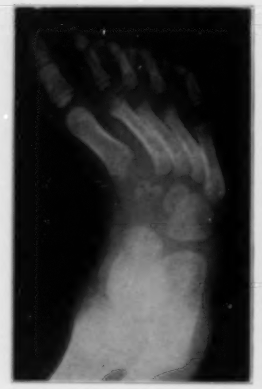

Fig. 3-A

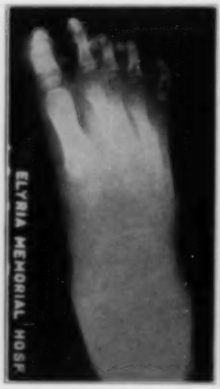

Fig. 3-B

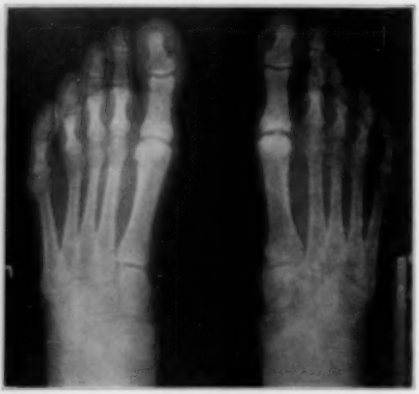

Fig. 3-C

Fig. 3-A: J. T. (Case 2). Roentgenogram made May 5, 1945, when the boy was five years old, showing severe metatarsus varus of the right foot.

Fig. 3-B: Roentgenogram made October 3, 1945, when the cast was removed, seven weeks after anterior capsulotomies.

Fig. 3-C: Roentgenogram of both feet made December 21, 1956, eleven years and four months after the operation.

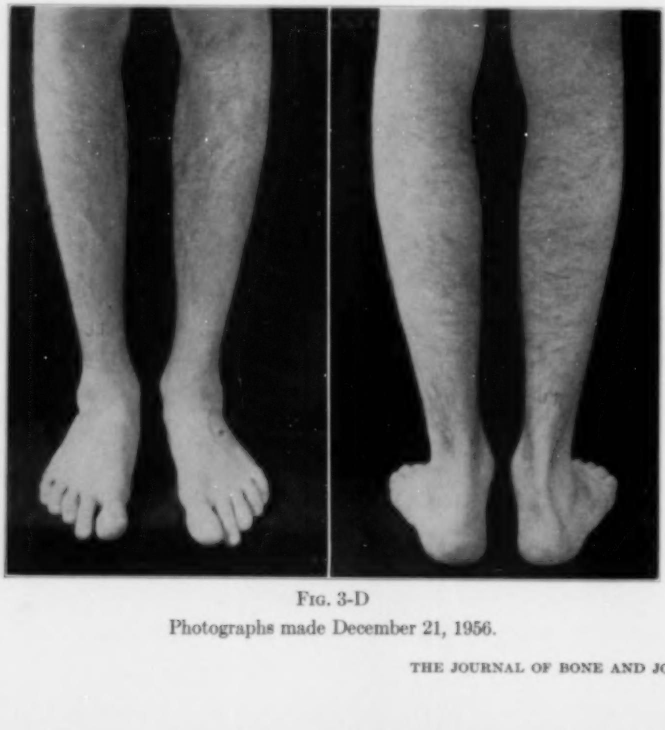

Fig. 3-D

Photographs made December 21, 1956.

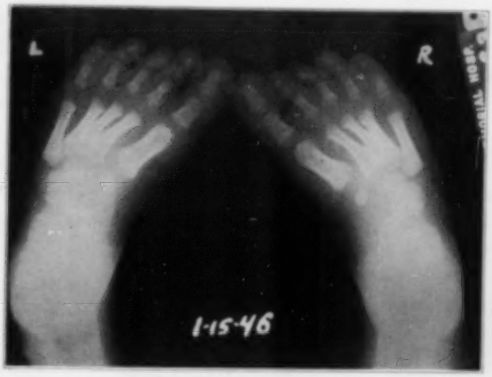

FIG. 4-A

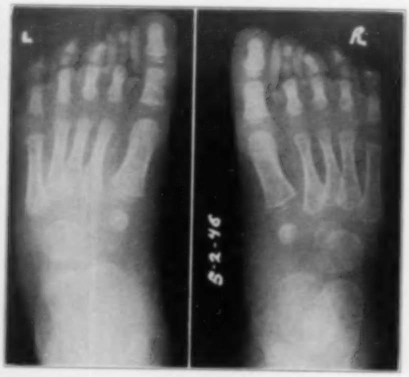

FIG. 4-B

Fig. 4-A: T. M. (Case 4). Roentgenogram of both feet made January 15, 1946, when the patient was two and one-half years old.

Fig. 4-B: Roentgenograms of both feet made May 2, 1946, three months after combined medial and anterior capsulotomies.

Fig. 4-C: Roentgenogram of both feet made January 4, 1957, eleven years after the operation.

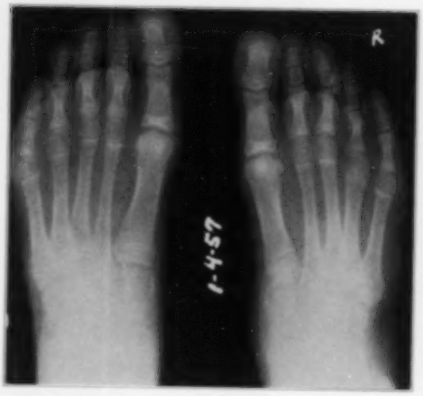

FIG. 4-C

surgeon for two and one-half years or more without success in correcting the deformity by any other means. Also, these children did not receive any further treatment for adduction of the fore part of the foot after the postoperative cast was removed.

In five patients with club-foot, medial capsulotomies, performed with techniques similar to those of Ober or Brockman, were done by us to correct the inversion component of the deformity, but this was not sufficient to correct the adduction deformity of the fore part of the foot. In two patients with club-foot, the medial and anterior capsulotomies were combined at the same operation. This is not recommended, however, because it necessitates a too long incision and too much dissection which entail more risk of postoperative impairment of the circulation. In four patients with more severe residual adduction in club-foot, transposition of the insertion of the tibialis anterior tendon to the lateral border of the foot was done in combination with anterior capsulotomies at the same operation. This may not have been necessary, but it was thought it would have a favorable influence against recurrence. In one of these patients (Case 10), the transposed tendon was re-implanted to the navicular bone because of overcorrection at the hind part of the foot. There was finally a good result.

## RESULTS

In some respects, the results in a few of the patients were difficult to evaluate. The purpose of the procedure is limited to the correction of the deformity of the fore part of the foot. We did not think that such correction would be possible by any non-operative means. While this condition may have been corrected satisfactorily and the result may be rated as *good*, the patient may still have required, for example, a triple arthrodesis to correct valgus deformity of the hind part of the foot. The important considerations are whether what was planned was accomplished, and to what extent did this operation improve the appearance and function of the foot. We also took into consideration the alignment of the

TABLE I

| Patient | Diagnosis | Age at Date of Operation | Duration of Post-operative Cast (*Weeks*) | Duration of Follow-up | Result |
|---|---|---|---|---|---|
| 1. J. B.* | Unilateral club-foot | 5 yrs. 6 mos. (7–25–45) | 10 | 11 yrs. 10 mos. | Excellent |
| 2. J. T. | Unilateral metatarsus varus | 5 yrs. (8–15–45) | 7 | 11 yrs. 9 mos. | Excellent |
| 3. K. F.*** | Bilateral club-foot | 3 yrs. 6 mos. | | 10 yrs. 9 mos. | |
| | | (11–28–45) Rt. | 9 | | Good |
| | | (12–12–45) Lt. | 8 | | Good |
| 4. T. M.*** | Bilateral club-foot | 2 yrs. 6 mos. | | 11 yrs. 4 mos. | |
| | | (1–16–46) Lt. | 12 | | Excellent |
| | | (1–30–46) Rt. | 12 | | Excellent |
| 5. W. T.* | Unilateral club-foot | 4 yrs. 9 mos. (3–7–46) | 10 | 10 yrs. 10 mos. | Good |
| 6. C. L.* | Unilateral club-foot | 6 yrs. (12–4–46) | 12 | 10 yrs. | Excellent |
| 7. F. D.** | Unilateral club-foot | 5 yrs. 6 mos. (11–3–48) | 6 | 8 yrs. 7 mos | Excellent |
| 8. J. L.** | Unilateral club-foot | 5 yrs. 8 mos. (11–3–48) | 11 | 8 yrs. 2 mos. | Excellent |
| 9. P. C. | Bilateral metatarsus varus | 4 yrs. 4 mos. | | 7 yrs. 2 mos. | |
| | | (8–31–49) Lt. | 8 | | Excellent |
| | | (9–14–49) Rt. | 8 | | Excellent |
| 10. R. C.** | Unilateral club-foot | 3 yrs. 8 mos. (5–10–50) | 12 | 6 yrs. 6 mos. | Good |
| 11. R. A. | Bilateral club-foot | 4 yrs. 9 mos. | | 4 yrs. 7 mos | |
| | | (6–25–52) Rt. | 9 | | Good |
| | | (7–2–52) Lt. | 8 | | Excellent |
| 12. J. Y. | Bilateral club-foot | 4 yrs. 7 mos. | | 4 yrs. | |
| | | (11–26–52) Rt. | 13 | | Excellent |
| | | (12–10–52) Lt. | 12 | | Excellent |
| 13. W. H.** | Unilateral club-foot | 5 yrs. (7–11–53) | 9 | 3 yrs. 10 mos. | Excellent |
| 14. D. I.* | Unilateral club-foot | 4 yrs. 9 mos. (9–9–53) | 14 | 3 yrs. 8 mos. | Excellent |
| 15. L. N. | Unilateral club-foot | 3 yrs. 8 mos. (7–21–54) | 10 | 2 yrs. 5 mos. | Poor |
| 16. T. M. | Bilateral metatarsus varus | 7 yrs. 2 mos. | | 2 yrs. 2 mos. | |
| | | (2–9–55) Lt. | 10 | | Excellent |
| | | (3–2–55) Rt. | 9 | | Good |
| 17. B. E.* | Unilateral club-foot | 3 yrs. 6 mos. (9–7–55) | 15 | 1 yr. 8 mos. | Fair |
| 18. A. C. | Bilateral metatarsus varus | 4 yrs. | | 1 yr. 3 mos. | |
| | | (1–5–56) Lt. | 16 | | Excellent |
| | | (1–12–56) Rt. | 14 | | Excellent |
| 19. E. Z. | Bilateral metatarsus varus | 3 yrs. 3 mos. | | 10 mos. | |
| | | (3–24–56) Rt. | 21 | | Excellent |
| | | (3–30–56) Lt. | 20 | | Excellent |
| 20. C. R.* | Bilateral club-foot | 5 yrs. 10 mos. | | 7 mos. | |
| | | (10–17–56) Rt. | 17 | | Fair |
| | | (10–31–56) Lt. | 15 | | Fair |

* Medial capsulotomies for inversion deformity preceded this operation.

** Combined with transposition of the insertion of the tibialis anterior to the lateral border of the foot.

*** Combined with medial capsulotomies at the same operation.

bones and their relationships as they appeared in the roentgenograms. This may or may not confirm the general impression of a good correction. Roentgenograms made several years later also gave information as to whether the operation had any harmful effect upon bone growth or caused any other disability.

The classification of results, accordingly, is recorded as objectively as we were able. By *excellent*, we mean that the foot had a practically normal appearance and normal function. A *good* result is one in which the appearance of the foot, deviating from the normal to only a slight or unimportant degree, is not anticipated to cause any symptoms or disability in the future and with which both we and the parents were well satisfied. A

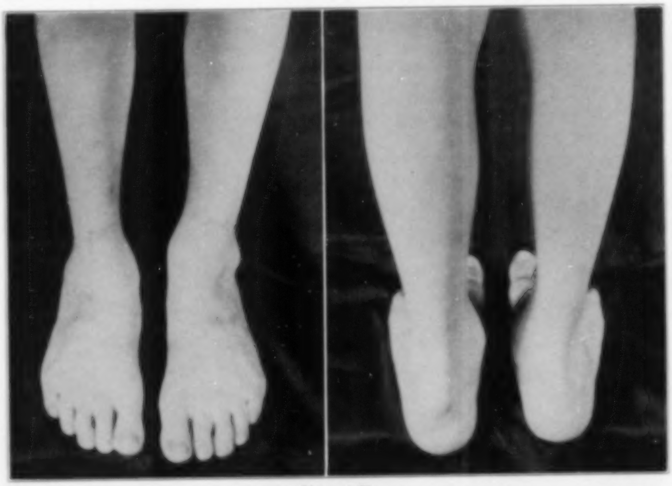

FIG. 4-D

Photographs made January 4, 1957.

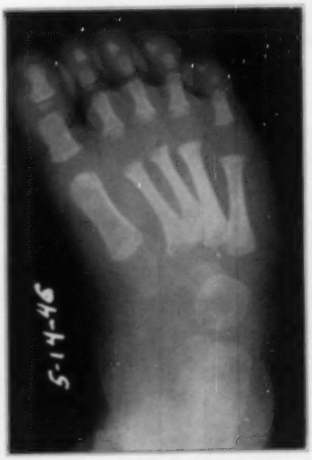

FIG. 5-A

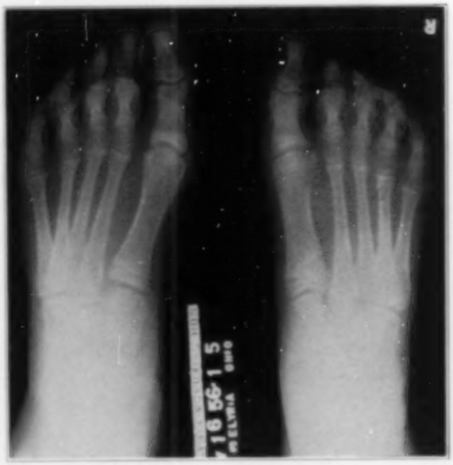

FIG. 5-B

Fig. 5-A: F. D. (Case 7). Roentgenogram made of the right foot May 14, 1946. Anterior capsulotomies operation and transposition of the insertion of the tibialis anterior tendon to the lateral border of the foot were done on November 3, 1948, when the child was five and one-half years old.

Fig. 5-B: Roentgenogram made of both feet November 16, 1956, eight years after the operation.

*fair* result is one with which we were not satisfied, but the deformity was not sufficiently severe to need any further corrective procedure. A *poor* result is one in which further treatment is necessary to correct the deformity of the fore part of the foot.

The duration of follow-up observations and the results following twenty-nine operations are shown in Table I. We considered that nineteen of the operations had excellent and six good results, and that these could not have been attained by any closed methods of treatment. Three had fair results. One patient had a poor result and requires a more radical procedure to correct deformity of the fore part as well as of the hind part of the foot. An analysis of the results as to the relative value of this procedure for the correction of club-foot and metatarsus varus is inconclusive in this small series of cases, but it is

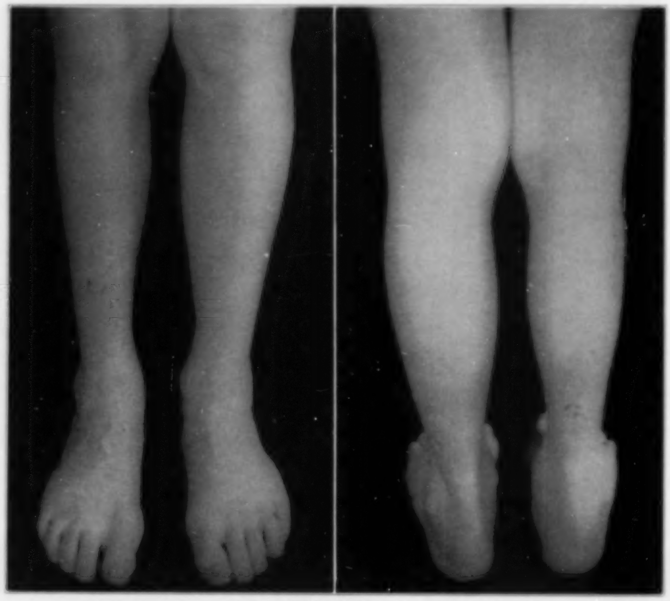

FIG. 5-C

Photographs made November 16, 1956.

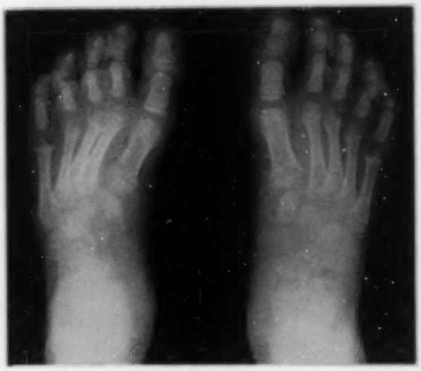

FIG. 6-A

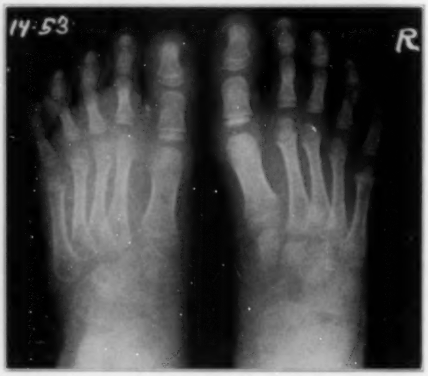

FIG. 6-B

Fig. 6-A: W. H. (Case 13). Roentgenogram of both feet made July 10, 1953, showing adduction deformity of the left foot, when the boy was five years old.

Fig. 6-B: Roentgenogram of both feet made September 14, 1953, immediately after the postoperative cast was removed, nine weeks after anterior capsulotomies.

suggestive. Of the twenty operations for club-foot, there were three fair results and one poor result. Of the nine operations in metatarsus varus, all the results were good or excellent.

We can only speculate why the results in some cases of club-foot were not as good as in others. The operation should not be done before the other components of the deformity have been corrected, but this is not always easy to determine. We suspected that the foot was not maintained in postoperative correction in the plaster cast long enough to prevent some recurrence. However, an analysis of the results shows no such relationship. It is more likely that some patients had already developed too much bone deformity for correction to be well maintained by joint mobilization alone. A persisting imbalance of muscle strength, of which B. E. (Case 17) is quite possibly an example, may also contribute to recurrence of the deformity. Although there was complete passive correction without resistance, the fore part of the foot was in the adducted position without support.

There are no sharply defined borderlines of age of the patient or severity of the deformity when it can be said that anterior capsulotomies alone, without additional measures, are sufficient for maintenance of correction, and roentgenograms in this age group were not particularly helpful in these determinations. We did not establish either a lower or an upper age limit at which the operation may be indicated or will no longer be effective. We can think of no reason why it should not be done earlier than three years of age, if necessary, because it does not endanger bone growth. In fact, it appears better to operate before this age in patients whose conditions are proving to be most resistant to correction.

Not every result, of course, was completely satisfactory. On the whole, we were well pleased with this procedure. As we gain more experience we shall learn more about its advantages and limitations. In selected cases of resistant adduction deformity of the fore part of the foot in patients up to and including seven years of age, it is decidedly preferable to more radical osteotomies, tarsometatarsal arthrodeses, or bone or joint resections in these still young children.

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## DISCUSSION

Dr. David S. Grice, Boston, Massachusetts: The authors have presented a simple technique for correcting persistent adduction deformity of the fore part of the foot and have demonstrated that adequate correction can be obtained with this method. They do not propose a radical procedure for adduction of the fore part of the foot in patients of all ages; this technique is restricted to a specific group of patients over three years of age who have been under treatment with plaster casts and exercise, but have residual deformity. They are also not advocating this procedure for older patients in whom the severe deformity involves the contour of the metatarsal shafts. This obviously is a limited group of patients, but one that we all encounter. The procedure advocated by the authors would seem well adapted to the group of patients that they have treated. We have no personal experience with this method but have applied the same principles to slightly older patients in whom there was deformity of the metatarsal shafts.

The operation we have used consists in a capsulotomy of the first metatarsal and the fifth metatarsal joint, and osteotomies of the bases of the second, third and fourth metatarsals. This procedure has resulted in successful correction of many of these deformities in older children. At times we have osteotomized all five metatarsals, and at other times we have done a capsulotomy on the first metatarsal joint with osteotomies on the lateral four. I see no reason why the capsulotomy of the joints would not result in excellent correction in the younger age group.

I wonder why Dr. Heyman apologizes for the necessity for a triple arthrodesis at a later date in order to correct the valgus deformity of the hind part of the foot. It seems to me that with some of these peculiar feet which have almost a Z-shaped contour, the first step should be the correction of adduction of the fore part of the foot. After obtaining a correct alignment of the distal tarsal joints and the metatarsals, it is then possible to correctly align the foot with a triple arthrodesis. If the reverse procedure is carried out, it may be very difficult to get a satisfactory appearing foot even if osteotomies of the metatarsals were done.

Dr. Joseph Hiram Kite, Atlanta, Georgia: The authors have presented what appears to me to be a very ingenious and useful operation for certain cases of club-foot and metatarsus varus. If club-foot were properly treated, we would not need this operation. However, club feet are not always straightened in the proper manner. If the adduction of the fore part of the foot is completely corrected at the beginning of the course of treatment, as it should be, there will be none to correct later. Adduction of the fore part of the foot occurs in those patients in whom attempts are made to bring the foot up in dorsiflexion before carrying the fore part of the foot out in full abduction. Treatment is often continued in dorsiflexion and the adduction is never completely corrected. The fore part of the foot finally becomes fixed in adduction and in some older children it cannot be corrected by casts.

The cases of metatarsus varus may be divided into two groups. One is that in which the deformity is very severe and difficult to correct, is frequently hereditary, and associated with other congenital deformities. Often, the heel is in a severe valgus position. I have had only about a dozen such cases in nearly 1,200 cases of the second group, in which the deformity, in infants, is mild. It is only for these patients in the severe-deformity group that this operation will be needed. In some of the older patients in this group, I have used casts for months without completely correcting the adduction of the fore part of the foot. I have excised the bases of the lateral four metatarsals in some of these patients after the method of Peabody. This gives a horrible looking roentgenogram, but finally a fairly satisfactory result. I have done oblique osteotomies through the bases of the metatarsals after the method of Max Lange, but did not get good correction in these cases. I have done wedge osteotomies through the cuneiform bones with fairly satisfactory results in some of these cases.

I believe that the operation of Dr. Heyman and Dr. Herndon is simpler and should give a better correction with less shortening of the fore part of the foot. I tried this operation on one resistant club-foot in a child who had been treated elsewhere. I was pleased with the ease of the operation and with the amount of correction obtained, and am planning to try it on additional patients who apply for treatment. Theoretically, it seems a good operation. With the experience of one case I would like to recommend it.

Dr. Herndon (closing): There are two points in technique that should be emphasized. There is apparently some concern over the transverse incision across the dorsum of the foot. In none of our patients was there trouble with skin healing, nor was there circulatory embarrassment in any patient or sensory deficit in the toes from nerve damage.

We always divide the plantar ligaments as well. I would also like to emphasize the necessity of dividing the intermetatarsal ligaments at their base as well as the tarsometatarsal ligaments.

It may be a little difficult particularly in the younger patients to find the tarsometatarsal joints, but if the procedure is performed with the roentgenogram in view, they can be demonstrated without damaging the articular cartilage. The second tarsometatarsal joint is somewhat proximal to the first. Once this joint is identified, there is little difficulty in locating the remaining joints.

We have not established age limits for this procedure. Our principles have been that we do not recommend the procedure in patients who have enough bone deformity to preclude the possibility of obtaining correction by means of a soft-tissue procedure. In most of the cases, however, incongruity of joint surfaces is demonstrable after correction has been achieved by capsulotomies. Unless this is severe, remodeling occurs at a fairly rapid rate.

I agree with Dr. Kite that many resistant club feet could be prevented with adequate early treatment. However, a few of our own patients who had the best treatment we are able to give, developed deformity. Regarding anomalous tendon insertions in metatarsus varus or in club-foot with resistant adduction of the fore part of the foot, we have observed an abnormal insertion in only one case, that of the tibialis anterior.

# Leg-Lengthening

## A Personal Follow-up of Forty Patients Some Twenty Years After the Operation*

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CHICAGO, ILLINOIS

*From the Shriners' Hospital for Crippled Children, Chicago*

The value of long follow-up studies needs no emphasis. Short-term studies like short-term bonds are of some value; but long-term studies, like long-term bonds, yield the highest dividends. This study of leg-lengthening results was facilitated by several factors.

1. All the patients were operated upon at the Shriners' Hospital in Chicago where, because of particular interest in the cases, careful records were kept and all roentgenograms, scanograms, photographs, measurements, and muscle charts are on file from the preoperative period to the present.

2. All operations in this series were performed by the same surgeon, Beveridge H. Moore, former Chief Surgeon of the Hospital, and in almost all instances the senior author of this paper was privileged to assist in the surgery.

3. The willing response of patients, now in their mid-adult years, in returning long distances to the hospital to spend the major part of a full day in exhaustive tests and studies, was most gratifying.

All forty patients included in this report were not operated upon exactly twenty-two years ago, but the average elapsed time since surgery was twenty-two years. The great majority of operations were performed more than twenty years ago; some were performed twenty-eight years ago.

In all cases follow-up data were obtained by personal, complete physical examinations combined with photographs, history, roentgenograms, and scanograms. While all three authors cooperated in the examinations, one author, Blair, was present at all forty examinations and, in order to reduce the inaccuracies of variables, his evaluations were considered final. All data were collected in a manner to satisfy pre-arranged forms, and especially designed punch cards were printed so that an adequate punch-card system could be employed for compilation of data. Another author, Millar, was made solely responsible for the punch-card system and his decisions for entering data in certain categories were final. Every effort was employed in an attempt to evaluate results as uniformly and accurately as possible.

### OPERATION

The operative technique instituted thirty years ago at the Shriners' Hospital in Chicago was employed relatively unchanged in all forty patients except that the technique necessarily varied to accommodate the tibia or the femur. The apparatus used, the technique employed, and the carefully considered indications and contra-indications were detailed in an article published in 1941 by Beveridge Moore. Since they are not particularly pertinent to this report they will not be elaborated upon. Suffice it to state that following the work of Putti in Italy and the early work of Abbott in this country interest was aroused in leg-lengthening and many surgeons attempted the operation. In the course of years many forms of apparatus were invented, some of which, by their complicated mechanisms and massive dimensions, resembled the torture machines of the Inquisition.

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* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 30, 1957.

Little heed was given to reasonable indications and contra-indications but large series of cases were built up. The general results a few years later were so poor that interest faded and the operation quite justifiably fell into discard. An indication of slackening of interest is shown in the series now being presented in which sixty-three patients were operated upon in the past twenty-eight years but only three of the sixty-three operations were performed in the past ten years.

Of the sixty-three patients, fifty-five lengthenings were done in the tibia, and eight in the femur. Renewed interest in extremity-lengthening in certain institutions now appears to favor lengthening the femur over an intramedullary rod. Only the passage of time and the sobering statistics of a long-term follow-up study will prove or disprove the wisdom of the more recent methods of lengthening. The apparatus used in the tibial lengthenings in this report was an outgrowth of modifications of one of the Abbott inventions and may be commended or condemned because of its simplicity. It employs the trombone method of obtaining extension and has no turnbuckles or adjustment screws. Perhaps it is too simple, but as statistics show, malalignment of the separated portions of the shaft was not a significant complication in this series of cases.

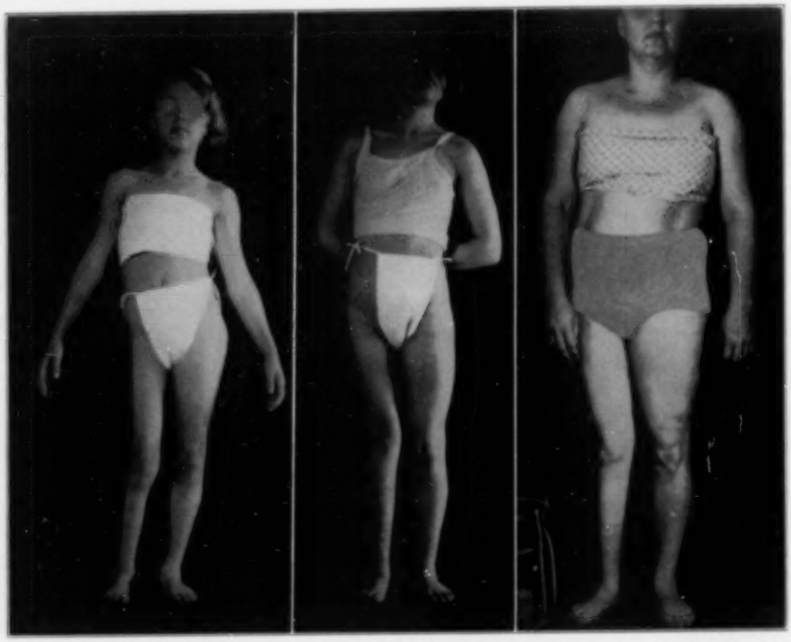

Fig. 1

L. T. G. The patient had poliomyelitis involving right lower extremity at age five. (Left): Preoperative photograph made at age thirteen when the discrepancy was two and one-half inches. (Center): At age fourteen, the postoperative tibial lengthening was two and one-half inches. (Right): At age thirty-nine, the discrepancy was one-quarter inch. There was loss of hip abductor power, and severe fatigue after walking only fifty feet. Total evaluation: *poor*.

In lengthening of the tibia, lengthening of the Achilles tendon was usually performed at the start of the operation. Following this, a segment of the lower portion of the shaft of the fibula was removed and the areas of Achilles tendon lengthening and fibula excision were closed. Double Steinmann-pin fixation was next done through both metaphyses. A third incision was made along the entire shaft of the tibia, the bone being bared by subperiosteal dissection. The periosteum was not cut transversely. A long Z-type osteotomy in the coronal plane was then made by means of drill holes and an osteotome. After soft-tissue closure, the leg was placed in the lengthening apparatus. In order to allow for soft-tissue repair, no attempt at lengthening was made for three days. Tension was then placed on the pins by means of daily tightening a wing nut at the distal end of the apparatus. Maximum lengthening was usually obtained within three weeks. Sufficient union to allow the application of a plaster cast usually was present in six to eight weeks. The maximum lengthening obtained in this series was three and three-fourths inches but this lengthening was not obtained without considerable discomfort to the patient. Unsupported weight-bearing was usually possible after four months.

## SELECTION OF CASES

Most of the patients selected for leg-lengthening were those with shortening of one extremity due to poliomyelitis. This diagnosis accounted for twenty-six of the forty cases. The remainder of the cases was distributed as follows: five cases of osteomyelitis or pyogenic joint disease, one case of tuberculosis of the hip, three cases of congenital shortening of an extremity, three cases of epiphyseal injury, and two cases of shortening due to old unreduced congenital dislocations of the hip. In the poliomyelitic patients two specific requirements had to be met.

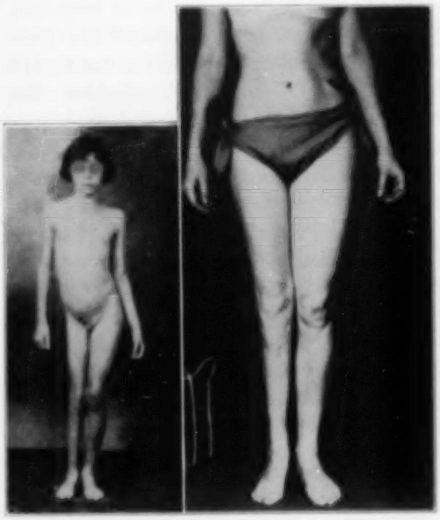

FIG. 2

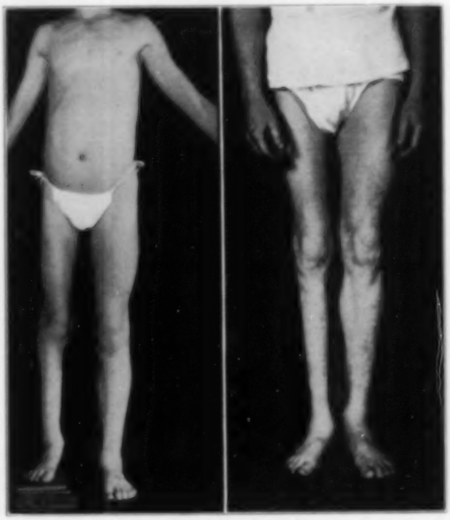

FIG. 3

Fig. 2: C. H. C. The patient had poliomyelitis of the right lower extremity at age two. (Left): At age ten the preoperative discrepancy was two and one-half inches. The tibia was lengthened two and one-quarter inches. (Right): At age thirty-three, the discrepancy was five-eighths inch, and the gait fair. Total evaluation: *improved*.

Fig. 3: R. T. The patient had poliomyelitis of the right lower extremity at age two. (Left): At age eight, the preoperative discrepancy was two inches. The tibia was lengthened two and one-half inches. (Right): At age twenty-seven, the limb length was equal, and the gait fair. Total evaluation: *improved*.

1. The gluteal muscles had to be of sufficient power to be rated as at least *fair*, so that the pelvis could be stabilized.
2. The quadriceps had to be strong enough to sustain extension of the knee against gravity even with a small amount of weight-exerting resistance. The quadriceps power had to be rated as *good*.

In other patients, no drainage from infected bones or joints within a two-year period prior to surgery was countenanced; general health conditions had to be good; and in the patient with tuberculosis of the hip the process must have been arrested. All patients were carefully measured. Results of muscle examinations were recorded, and roentgenograms and photographs were made prior to surgery. During the lengthening procedure roentgenograms were made at frequent intervals in order to observe the alignment and to measure the lengthening. In the years immediately following operation further examinations were made and roentgenograms and photographs obtained.

### GENERAL OBSERVATIONS

Complications which seemed most likely to occur and which might have been regarded as conclusive condemnation of the procedure failed to materialize in the study. Serious infections involving bone occurred in only three instances, all in patients with old pyogenic joint diseases which had been considered arrested and from which no drainage had been present for at least two years. Apparently the trauma of the operative procedure was sufficient to reactivate the temporarily quiescent infection. No non-union and no long-delayed union occurred. Angulation of moderate degree developed in several patients but was corrected without undue difficulty. Transitory neurological changes were experienced in five patients and permanent loss occurred in two. Vascular complications were rare and of no permanent importance. Dislocation of the hip was caused in one patient. Pin-hole drainage was only temporary but oedema of the extremity continued for a considerable length of time.

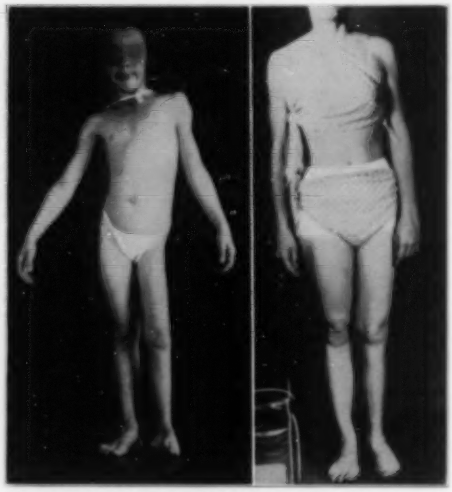

FIG. 4

D. O. The patient had poliomyelitis of the left lower extremity at age eighteen months. (Left): At age nine, the discrepancy was one and one-half inches. Preoperative discrepancy at age twelve (not illustrated) was three inches. The tibia was lengthened two and one-half inches. (Right): At age thirty-two, the overgrowth of the lengthened leg was three-eighths inch. Total evaluation: *improved*.

### BENEFICIAL RESULTS

When interviewed and examined twenty to thirty years after leg-lengthening, practically all patients were pleased and enthusiastic about their results. The men were surprisingly successful in their chosen fields, only a few required totally sedentary work. Several were accomplished engineers, bankers, and mechanics. The women were able to carry on the vigorous duties of housewives as well as of office workers. Their infirmities interfered very little with their activities. If this survey had been made by mail rather than by personal examination a false idea might have evolved because critical examination uncovered a number of things that upon appraisal seemed undesirable.

The appearance of the limbs and the fairly horizontal positioning of the pelvis were cosmetically satisfactory and an improvement over preoperative conditions. In standing, the body was erect and well balanced. Valgus deformities of the knee were of slight notice and had not been radically increased by the lengthening procedures or by the passage of years.

One of the most remarkable findings was the maintenance of leg length after the operative procedure was long past. In thirty-five of the forty patients the lengthened limb continued its lengthened measurement into adult life. As these limbs were steadily becoming relatively shorter before surgery, the maintenance of leg length actually represented a continued growth stimulation which did not cease in one, two, or three years after the bone was well healed and the circulation apparently restored to its preoperative condition. It is evident that the stimulation for increased longitudinal growth induced by the trauma of surgery exerted its influence all through the remaining growing years. In five patients the stimulation for growth was so powerful that the previously short legs actually outgrew the healthy legs. These patients with some residual weakness present in legs longer than their healthy legs exhibited poorer function than those still possessed of a deficit in length of their weak legs.

On the credit side it should be stated that the major complications listed in papers as probable deterrents to attempting leg-lengthening operations were conspicuously absent. There was no non-union, no severe vascular disturbance, no significant bone angulation, or no debilitating neurological defect. Late fracture of a lengthened bone occurred in only two patients and in both, healing progressed in satisfactory manner.

## UNDESIRABLE COMPLICATIONS

Individually the most severe complication was amputation of a limb below the knee in a patient with congenital bowing of the tibia. Amputation was elected because of persistent skin break-down in an adherent scar. This limb probably should have been amputated rather than subjected to lengthening.

There were less obvious complications which produced some disability. Adherent scars with breakdown of the epithelium were present in two patients. Coldness of the limb and relative shortness of the foot were common complaints. Most of these patients had had poliomyelitis, and the latter two complications are known to be common regardless of operation. Rather interestingly, only three of the forty patients wore one shoe of greater size than the other. The remainder preferred to adjust to equal sized conventional footwear by means of various fillers. Only five patients wore any elevation on their shoes. Other patients, for whom shoe lifts might have been ordered if they had been seen more frequently in clinics, had found by trial and error that they walked better without shoe lifts. Their decisions were probably more sensible than ours would have been.

In practically all of the patients in whom the tibia had been lengthened, there were foot deformities of some degree. Undoubtedly many foot deformities would have existed even if no lengthening operation had been performed; however, personal appraisal led to the conclusion that pre-existing foot deformities had been aggravated and new foot deformities had been initiated by the lengthening procedure. These foot deformities remained in spite of triple arthrodeses performed either prior to lengthening or subsequent to lengthening. A commonly recurring complication was rigidity of multiple joints of the feet. Many feet which were fairly loose before leg-lengthening later had rigid valgus deformities.

One of the most constant complications, despite lengthening of the Achilles tendon was increasing equinus deformity of the foot. In spite of lengthening, tenotomy, and the use of foot supports on the lengthening frame, equinus deformity became established and became aggravated as leg-lengthening increased. Unquestionably the predominance of residual foot deformities beyond those anticipated without lengthening procedures detracted somewhat from successful appraisal of the operation.

In a few cases increased knock-knee and increased outward tibial twist adversely affected the performance of the limb; however, such complications occurred but seldom.

## PRINCIPAL FAULT OF LEG-LENGTHENING

If only these advantages and disadvantages were balanced against each other, one could probably justify the operation in the majority of patients. There was, however, one big fault which became increasingly evident as the forty patients were seen and the results tabulated twenty to twenty-eight years after surgery. This very disturbing fault was that compared with the preoperative muscle evaluations the evaluations in the adult

TABLE I

TABULATION OF FORTY PATIENTS AFTER LEG-LENGTHENING — PERSONAL FOLLOW-UP

| Case | Patient | Diagnosis | Bone Lengthened | Age at Surgery (*Years*) | Date of Surgery | Age at Follow-up (*Years*) | Years Follow-up | Preoperative Discrepancy (*Inches*) | Length Obtained (*Inches*) | Follow-up Discrepancy (*Inches*) | Complications | Loss of Muscle Power | Gait | Total Evaluation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | J. B. | Polio. | Tibia | 13 | 3-26-29 | 41 | 28 | 2 | 1 3/8 | 1 | Transient paralysis, peroneal nerve | None | Fair | Improved |
| 2 | F. D. | Polio. | Tibia | 10 | 1-30-30 | 38 | 27 | 2 6/8 | 1 5/8 | 2 | Wound infection | None | Fair | Unchanged |
| 3 | E. W. | Polio. | Tibia | 13 | 2-9-30 | 38 | 27 | 2 | 1 4/8 | 2 | Late fracture of tibia | None | Fair | Improved |
| 4 | R. S. | Polio. | Tibia | 13 | 3-27-30 | 39 | 27 | 2 6/8 | 2 4/8 | Overgrowth 2/8 | Valgus ankle; failure fibula lengthen | Hip abductors | Fair | Improved |
| 5 | W. Ra. | Polio. | Tibia | 11 | 5-15-30 | 37 | 26 | 1 1/8 | 1 1/8 | 1 | None | Knee flexors, extensors | Poor | Worse |
| 6 | L. T. | Polio. | Tibia | 13 | 8-7-30 | 39 | 26 | 2 4/8 | 2 4/8 | 3/8 | None | None | Poor | Worse |
| 7 | W. R. | Polio. | Tibia | 11 | 9-18-30 | 38 | 26 | 2 | 2 | 1 | None | None | Fair | Improved |
| 8 | V. R. | Polio. | Tibia | 14 | 9-25-30 | 40 | 26 | 2 6/8 | 2 5/8 | 5/8 | Valgus knee required osteotomy | None | Poor | Worse |
| 9 | E. D. | Polio. | Tibia | 9 | 1-21-32 | 33 | 25 | 2 | 2 4/8 | 1 3/8 | None | None | Fair | Improved |
| 10 | F. D. | Polio. | Tibia | 10 | 2-14-33 | 34 | 24 | 1 3/8 | 1 5/8 |  | None | None | Excellent | Improved |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | C. H. | Polio. | Tibia | 10 | 10–12–33 | 33 | 23 | 2⅝ | 2⅜ | ⅝ | Transient peroneal paralysis | Foot; plantar peroneals | Fair | Improved |
| 12 | E. B. | Polio. | Tibia | 13 | 3–22–34 | 37 | 22 | 2 | 2⅜ | ⅝ | None | None | Fair | Improved |
| 13 | R. Mc. | Polio. | Tibia | 13 | 3–29–34 | 35 | 22 | 1⅝ | 3⅝ | Over-growth ⅜ | None | Hip, flexors, extensors; knee, extensors | Poor | Worse |
| 14 | J. G. | Polio. | Tibia | 9 | 4–10–34 | 32 | 22 | 1⅝ | 2⅞ | ⅝ | Delayed wound healing; late fracture | None | Excellent | Improved |
| 15 | H. H. | Epiphyseal injury | Femur | 14 | 8–9–34 | 36 | 22 | 3⅜ | 1 | 3⅝ | Pins broke (mechanical) | None | Poor | Unchanged |
| 16 | W. Mc. | Polio. | Tibia | 13 | 10–4–34 | 35 | 22 | 1⅝ | 1⅝ | 1⅜ | Skin slough required graft | None | Excellent | Improved |
| 17 | J. C. | Congenital short femur | Femur | 8 | 1–29–35 | 29 | 22 | 4 | | 6⅜ | Delayed wound healing | None | Fair | Worse |
| 18 | D. W. | Septic arthritis | Femur | 9 | 7–18–35 | 31 | 21 | 2⅝ | 2 | 1⅝ | Partial ankylosis of knee | None | Excellent | Improved |
| 19 | D. G. | Congenital dislocation of hip | Femur | 13 | 8–8–35 | 34 | 21 | 2⅝ | ⅝ | 4 | None | None | Fair | Worse |
| 20 | S. H. | Epiphyseal injury | Tibia | 10 | 9–12–35 | 31 | 21 | 1⅝ | 1 | 1⅜ | Angulation of tibia | None | Excellent | Improved |
| 21 | M. K. | Tuberculosis of hip | Femur | 11 | 9–17–35 | 33 | 21 | 4 | 2 | 2⅝ | Pin migration (mechanical) | None | Fair | Improved |

TABLE I (*Continued*)

| Case | Patient | Diagnosis | Bone Lengthened | Age at Surgery (*Years*) | Date of Surgery | Age at Follow-up (*Years*) | Years Follow-up | Preoperative Discrepancy (*Inches*) | Length Obtained (*Inches*) | Follow-up Discrepancy (*Inches*) | Complications | Loss of Muscle Power | Gait | Total Evaluation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | M. M. | Polio. | Tibia | 8 | 1-21-36 | 29 | 21 | 1 4/8 | 2 | | Fracture of tibia 1 year after surgery | None | Excellent | Improved |
| 23 | M. W. | Polio. | Tibia | 11 | 3-26-36 | 30 | 20 | 1 4/8 | 1 5/8 | 2/8 | Temporary peroneal paralysis | Hip abductor; knee flexors | Fair | Worse |
| 24 | C. G. | Congenital dislocation of hip | Femur | 12 | 4-2-36 | 32 | 20 | 1 4/8 | 1 3/8 | 4 | Flexion deformity of knee | None | Fair | Worse |
| 25 | D. O. | Polio. | Tibia | 12 | 4-9-36 | 32 | 20 | 3 | 2 4/8 | Overgrowth 3/8 | Flexion deformity of knee | Hip abductor | Fair | Improved |
| 26 | M. S. | Polio. | Tibia | 11 | 7-23-36 | 31 | 20 | 1 4/8 | 2 | 3/8 | Temporary peroneal paralysis | None | Fair | Improved |
| 27 | W. S. | Polio. | Tibia | 9 | 8-13-36 | 29 | 20 | 2 | 1 6/8 | 1 2/8 | Ulcer on dorsum of foot | None | Fair | Improved |
| 28 | J. Sl. | Polio. | Tibia | 9 | 6-29-37 | 29 | 20 | 1 | 2 4/8 | Overgrowth 1 | None | Hip abductors | Fair | Improved |
| 29 | J. S. | Polio. | Tibia | 10 | 7-22-37 | 29 | 20 | 1 4/8 | 2 2/8 | 1 2/8 | None | None | Fair | Unchanged |
| 30 | V. W. | Polio. | Tibia | 12 | 8-12-37 | 32 | 20 | 1 4/8 | 1 6/8 | Overgrowth 1 | None | Hip abductor; knee extensor | Fair | Improved |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | B. H. | Congenital short femur | Tibia | 13 | 9–28–37 | 32 | 20 | 4⅛ | 2⅛ | 2 | Transient peroneal paralysis | None | Excellent | Improved |
| 32 | J. P. | Polio. | Tibia | 12 | 5–3–38 | 31 | 18 | 2 | 2 | 1 | Flexion deformity of knee | Hip abductors | Fair | Worse |
| 33 | R. T. | Polio. | Tibia | 8 | 7–26–38 | 27 | 18 | 2 | 2⅛ | | None | Hip abductors | Fair | Improved |
| 34 | H. G. | Polio. | Tibia | 8 | 9–15–38 | 27 | 18 | 1⅛ | 1⅞ | ⅛ | None | Plantar flexors | Fair | Unchanged |
| 35 | F. C. | Septic hip | Tibia | 15 | 2–1–40 | 33 | 17 | 3⅛ | ⅝ | 3⅛ | Angulation of tibia; wound infection | None | Fair | Unchanged |
| 36 | J. A. | Osteomyelitis | Tibia | 11 | 11–28–40 | 28 | 16 | 3⅜ | 1⅜ | 2⅜ | None | None | Fair | Improved |
| 37 | B. W. | Congenital hemiatrophy | Tibia | 8 | 5–7–42 | 22 | 14 | 1⅛ | 2 | ⅞ | Skin slough of foot following triple arthrodesis | None | Fair | Worse |
| 38 | M. D. | Epiphyseal arrest | Tibia | 13 | 6–25–42 | 28 | 14 | ⅝ | 1 | ⅜ | None | None | Excellent | Improved |
| 39 | S. K. | Septic dislocation of hip | Tibia | 15 | 4–3–47 | 25 | 10 | 3 | 2 | 3⅝ | Neurological deficit; wound infection; chronic osteomyelitis | Hip abductors, flexors; dorsiflexors of the foot | Poor | Worse |
| 40 | G. C. | Chronic osteomyelitis | Tibia | 13 | 10–30–47 | 23 | 9 | 2⅝ | 3⅜ | Overgrowth ⅛ | Pin-site drainage; peroneal hyperaesthesia | Dorsiflexors | Fair | Improved |

were decidedly weaker. Hip muscles that prior to surgery were rated *good* became only *fair* after leg-lengthening and muscles that were *fair* before surgery dropped to *poor* after leg-lengthening. The hip muscles, particularly the abductors of the hip, seemed to suffer the greatest loss of power and loss was more evident in cases of tibial lengthening than in cases of femoral lengthening. The observation of decreased muscle power was made in the years immediately following operation but it was presumed that with the passage of years return to preoperative muscle power would occur. This optimistic hope was not realized in the statistics. If any further change at all occurred, it was toward further weakening of the affected muscle groups. It soon became apparent that while improvement in appearance resulted from leg-lengthening, such lengthening was not synonymous with improvement of function. A typical case was that of a patient who noted that he could not swim or play basketball as well after lengthening as he could before. Two patients were required to wear long braces after leg-lengthening.

Even patients who had excellent musculature of the extremity prior to lengthening suffered appreciable loss of muscle power after lengthening, and such loss was not regained. The inescapable conclusion was that increased length of a limb required increased muscle power to control the lengthened lever and necessary increase in muscle power did not occur. Therefore, the muscle power suffered a relative loss in the control of the lengthened lever and with such loss performance or function diminished. The function of an extremity decreases with additional length obtained by operative methods of lengthening and such decrease adversely affects the performance of the extremity.

## CONCLUSIONS

It would appear that leg-lengthening operations are seldom justified. While there is understandable hesitancy in operating on a healthy, normal longer leg in order to arrest epiphyseal growth or to cause immediate shortening by osteotomy, such procedures under present conditions of control are fraught with less danger and are less formidable than are leg-lengthening procedures. No method of epiphyseal stimulation is as yet well enough established to warrant serious consideration but one cannot avoid the idea that even if epiphyseal stimulation should be successfully evolved and increased longitudinal growth produced, the muscle power would probably suffer relative loss similar to that occurring in leg-lengthening procedures. The same disadvantage of increasing lever length in the presence of already weakened muscles would apply.

If a patient is old beyond the chance of epiphysiodesis causing satisfactory reduction in leg-length inequality and if the over-all stature of a patient is so short that any reduction of height by leg-shortening is undesirable, leg-lengthening might be considered. On occasion parents absolutely refuse to permit any surgery on the good leg. In such a case leg-lengthening might be considered. If considered, the following criteria should be met.

1. Adequate muscle power should be present about the hip and thigh to control the lengthened unit.
2. Shortening of at least one and one-half inches must be present to justify such a formidable procedure.
3. A maximum gain of not more than three inches should be attempted.
4. Good bone and joint structures should be present, lengthening being contraindicated in cases of old osteomyelitis and old joint disease.

In the final analysis, prevention rather than correction of leg-length inequality is the most desirable goal, and it is along these lines that the greatest efforts should be expended. The truth of this statement is brought sharply to attention if for a moment one imagines that if the present-day armamentarium of vaccines and antibiotics had been available three decades ago, all thirty-nine cases of poliomyelitis and the eight cases of pyogenic hip disease might have been eliminated leaving only the cases of congenital deformities or epiphyseal injuries to contend with. Regardless of how the future may assist in improving these conditions, we cannot escape the fundamental concept that improved function, not just increased length, is the objective, and that these terms are not synonymous. This fact is clearly underlined by the end results in these patients studied some twenty to twenty-eight years after their original surgical procedures had been performed.

1. Moore, Beveridge H.: A Critical Appraisal of The Leg Lengthening Operation. Am. J. Surg., **52**: 415-423, 1941.

## DISCUSSION

Dr. George O. Eaton, Baltimore, Maryland: Leg-lengthening has become so rare an operation in our community that recently one of our residents could not identify the Abbott leg-lengthening apparatus when he found it in the equipment room. It is interesting that 84 per cent of the lengthenings reported were done between 1929 and 1940 and only 16 per cent were done in the following fifteen years.

At the Children's Hospital School in Baltimore, fourteen leg-lengthenings were done between 1931 and 1948. All were done for poliomyelitis and all were lengthenings of the tibia and fibula by means of the groove-and-tongue type of osteotomy and the Abbott distraction frame. The average age of the patient was fourteen and one-half years and the average gain in length was 5.48 centimeters. In ten of our fourteen patients, the amount of lengthening obtained approximately equalled the amount of shortening to be overcome. Only five out of the fourteen patients escaped some type of complication, and some had multiple complications, such as infections, anaesthesia with trophic ulcers, and delayed union. We saw one patient twenty-two years after operation. He had had an uncomplicated convalescence and no disability of neighboring joints attributable to operation. It was interesting to note on roentgenographic study that a normal-looking medullary cavity had been established throughout the length of the bone. On the basis of our experience, we feel that the procedure is most applicable in the tibia. Lengthening of a tibia in a leg with normal musculature done because of growth deficiency of the femur due to osteomyelitis was attended by major complications.

Attempted lengthening of a congenitally shortened femur, with more or less normal musculature, failed because of multiple complications. Leg-length equalization by means of leg-shortening seems to offer a much greater degree of success with much less hazard.

Dr. C. H. Crego, Jr., St. Louis, Missouri: My interest in bone-lengthening procedures dates back to the early days of my resident training at the Shriners' Hospital for Crippled Children in St. Louis, shortly after my former chief, Dr. LeRoy Abbott, had done his first lengthening of the tibia and fibula. It is a matter of historical interest that the first lengthening was done in December 1924. Abbott's original apparatus was quite crude and most complicated; the patient undergoing the lengthening procedure had to be continually checked and re-checked with repeated adjustment of the turnbuckle in order to control the tendency to anterior angulation. In the early patients, our major concern was that of controlling anterior angulation. After the first three or four legthenings were done with Abbott's original apparatus, repeated mechanical refinements were made, all of which were directed toward better control of anterior angulation.

We went from the use of two pins to three pins and finally to four pins in an apparatus quite similar to that of Dr. Sofield before we were able to control this anterior angulation. We have done all lengthenings since 1927 with that apparatus. At the St. Louis Unit of the Shriners' Hospital for Crippled Children, approximately seventy lengthening operations on the tibia and fibula have been done, only five having been done since 1937. Our experiences with these parallel those of Dr. Sofield and his associates as far as the development of major complications is concerned. Severe infections did not occur in tibial lengthenings. After the introduction of the four-pin apparatus, no appreciable degree of anterior angulation developed. There were no early vascular complications and in only one patient was there involvement of the common peroneal nerve. This was due to the placing of the upper pin too close to the nerve.

We are in complete agreement with the authors that very few patients with residual poliomyelitis are candidates for this operation. As early as 1930, we concluded that the only patients with poliomyelitis in whom this operation is indicated are those at the age of thirteen or fourteen in whom there is an inch and a half or more of shortening and in whom there is a normal or near normal musculature about the hip and knee. Almost satisfactory results have been obtained in patients with arthrodesed hips and arthrodesed knees, in whom shortening was a definite handicap.

Dr. Sofield and his associates have also mentioned growth arrest and bone-shortening; I feel that there is a definite place for both of these procedures. Growth arrest is the simplest means for overcoming leg-length inequality in growing children. Bone-shortening is a little bit more difficult than epiphyseodesis and hospitalization and convalescence are more prolonged. The results of this operation, however, have been excellent.

Dr. Garry de N. Hough, Springfield, Massachusetts (*by letter*): Our experience with leg-lengthening procedures at the Springfield Unit of the Shriners' Hospital for Crippled Children has been strikingly similar to that reported by Dr. Sofield and his associates. Starting at approximately the same time after the original work of Dr. Abbott, forty-three operations were done for inequalities varying from two and one-half to six inches. Although numerous complications were encountered, these were rarely severe. They were primarily infections. In more than half of the patients the cause of the shortening was due to poliomyelitis. Only two procedures have been done since 1950. Disturbance of the ankle joint is minimized by inserting the distal pin through the distal fibular fragment. By this, the malleolar relationship is not altered.

In spite of Dr. Sofield's findings indicating that late function is disturbed, presumably by increased leverage incidental to greater leg length, we believe that the procedure is a useful method of equalizing leg-length discrepancy in carefully selected cases. Improved medical care has fortunately made the operation less frequently necessary, but we believe very strongly that it should not be allowed to pass into oblivion.

## DISCUSSION

### Flexor-Tendon Injuries of the Fingers and Thumb

*(Continued from page 262)*

principles of reconstructive surgery: the injunction against working in a potentially contaminated field. If you play with fire, you will eventually get burned. The primary treatment must be such that a secondary procedure is not compromised.

This paper has succeeded, I believe, in clarifying our ideas on how to handle this difficult problem in tendon surgery. I am sure that Dr. Van't Hof will want to add to his survey the results of Pulvertaft[b], a series of ninety grafts for loss of both flexors as well as a most interesting report of grafting of the profundus alone in twenty-two cases. This report compares the results of early motion with those of a full three-week period of splinting and shows that the old principle of rest for an adequate time is still the method of choice; for he noted three instances of rupture of the graft due to early motion.

It should be pointed out that the results of secondary grafting depend upon three factors: the condition of the tissues, often altered by ill-advised primary treatment, the principles, and the technique. I reported[a] the results of 300 consecutive flexor-tendon grafts in the fingers, comparing the results when there were variations in one or more of these three factors. In the presence of damaged tissues, such as scarring and stiff joints, the results were poorer than in the ideal cases. It was also shown that use of the palmaris longus gave a better result than the use of the sublimis as a graft in comparable cases. Furthermore, with the latest technique, complete excision of the sheath, restoration of the fascial sling at the middle-joint level, and full-length tendon graft with tendon-to-bone insertion, the results were considerably improved.

In conclusion, Dr. Van't Hof's paper proves that secondary tendon grafts gave better results than primary repair for damage of the tendons in "no-man's land," and that the principle of simple wound closure and later reconstruction should be followed rigidly in this group. Until someone develops a better technique and reports it with a comparable series of consecutive cases, I believe that this should be our teaching and practice.

a. Boyes, J. H.: Evaluation of Digital Flexor Tendon Grafts. Am. J. Surg., **89:** 1116–1119, 1955.
b. Pulvertaft, R. G.: Tendon Grafts for Flexor Tendon Injuries in the Finger and Thumb. A Study of Technique and Results. J. Bone and Joint Surg., **38-B:** 175–194, Feb. 1956.

# Three-Side Plate Fixation for Fractures of the Femoral and Tibial Shafts

BY DONALD V. MARSHALL, F.R.C.S. (ED.), YORK, ENGLAND

*From the City Hospital, York*

This article is a preliminary report on a method of internal fixation used during the last seven years. In our series the results of this method have been encouraging, but a study of a larger series covering a longer period of time and handled by several surgeons will be necessary before the procedure can be properly evaluated.

The chief principle of this method is to hold the fractured bone on three sides in such a way that compression of the bone substance is avoided and that, as far as possible, the pressure either is confined to narrow linear areas or is distributed over so large an area that undesirable effects such as necrosis do not occur (Fig. 1). This principle appears especially valuable in the light of reports by Sir Reginald Watson-Jones and by Adams and Coonse of the unfavorable effects caused by compression when dual plates are fixed or bolted on opposite sides of the bone. The holding power of the three-side plate assembly is better than that of dual or single plates.

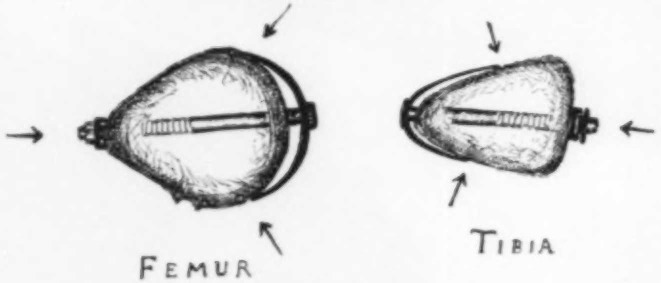

FIG. 1

Cross-section drawings showing the three-side plate assembly applied to the femur (left) and to the tibia (right). The arrows indicate the holding planes.

In the femur the three-side plate assembly is suitable for fractures of the middle and lower portions of the shaft and may therefore be considered complementary to intramedullary nailing which is suitable for fractures of the middle and upper portions of the shaft.

In the tibia the three-side plate assembly provides better holding power than does a linear plate and is perhaps easier and quicker to apply. The patient's convalescence is pleasanter, for he is more mobile and comfortable in his own home.

In the past the use of plates to treat fractures has resulted in a great deal of trouble; sepsis has developed and the metals used have been found to be unsuitable. Since the advent of antibiotics and the production of Vitallium and certain stainless steels, however, these difficulties have mainly disappeared and the use of plates has become practical. This type of fixation, when properly done, has the advantage of restoring fractured bones to their original line and position so that when union occurs, no new or unusual strains are placed on the joints and the full length of the limb is maintained. These two advantages are of considerable importance in the treatment of fractures of the lower extremity because of the heavy strains placed on this limb by walking and weight-bearing.

With the exception of methods recently described by surgeons in the United States (Wenger's method described in 1946 and Peterson and Reeder's method described in 1950), the only accepted method in the past has been the use of a linear plate held by screws. In this method the screws are inserted through holes in the plate, a procedure which sometimes results in difficulties, for it may prevent impaction of the bone, which is now thought to be desirable for healing and calcification, and the screw holes may coincide with cracks in the bone. Eggers modified this method by the use of slots, thus overcoming both the above difficulties and making possible further impaction of the bone as a result of muscular action following closure of the wound.

The slotted plates of Eggers and others, while representing a definite advance, do not hold the bone sufficiently firmly to allow free ambulation during the period of convalescence. Patients with tibial fractures must wear an above-the-knee plaster cast, and patients with femoral fractures cannot walk at all, traction splinting and bed rest being still required. So far as the author knows, Wenger, and Peterson and Reeder are the only surgeons to describe methods which enable the patient to be freely mobile with full weight-bearing during the period of convalescence.

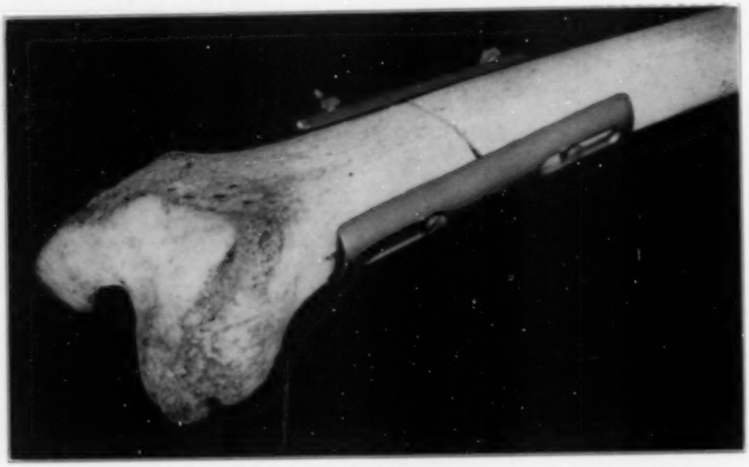

FIG. 2

Photograph showing the original type of three-side plate assembly applied to a fracture in the lower portion of the femoral shaft.

Wenger used a dual-plate assembly, a device which he reported as having given a number of satisfactory results. This type of assembly probably requires a rather large exposure in the thigh, however, and appears to be too bulky for use in the lower third of the tibia. Peterson and Reeder's method consisted in inserting slotted plates at right angles. In fractures of the femur, this method requires at least twelve screw holes and the making of a large incision.

In 1947, the author operated upon a patient with a supracondylar fracture of the femur. The fragments in this fracture were in the usual unsatisfactory position. An ordinary four-holed Venable Vitallium plate was used. Shortly after the operation, one of the screws in the distal fragment sheared off and the fragments became redisplaced. Dissatisfaction with this result directed the author's thought toward some different way of treating these fractures.

In 1948, the author began to search for a method which would make possible full weight-bearing and active walking as soon as the operative wound was healed.

It was evident that the ordinary type of plate lacks proper holding qualities. After trying out different methods on a wooden model of the femur, it was found that a device which holds the bone on three sides gives much firmer fixation than does the usual type of single flat plate with screws. For instance, it was found experimentally that the single flat plate, when optimumly placed on the femur or the tibia, could not withstand a stress greater than twenty pounds and that, when poorly placed, this plate could be displaced by a stress of only seven to twelve pounds. The original device devised for the femur by the author was found to withstand a stress of eighty pounds applied in any direction (Fig. 2). Later modifications have resulted in this device's being able to withstand stresses of 112 pounds applied in any direction.

In January 1949, this plate assembly was successfully used to treat a fracture of the lower portion of the femoral shaft; the patient was able to get up one month after the operation and to walk on his fractured limb two months after the operation. The fragments were firmly united at the end of three months and the patient was able to return to work.

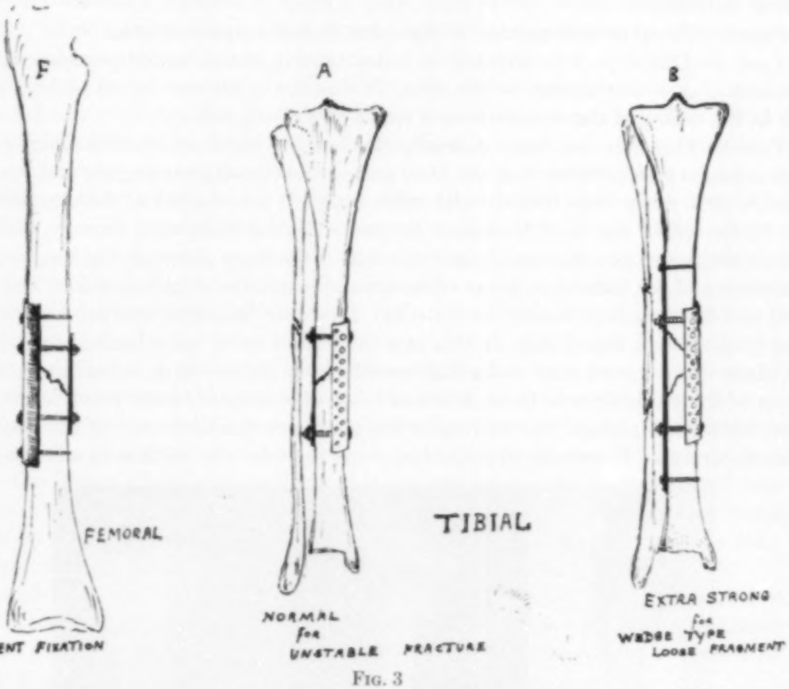
F
A
B
FEMORAL
PRESENT FIXATION
TIBIAL
NORMAL for UNSTABLE FRACTURE
EXTRA STRONG for WEDGE TYPE LOOSE FRAGMENT

FIG. 3

Line drawings which show: *F*, the present type of assembly used to treat femoral fractures; *A*, the present type of assembly used to treat unstable tibial fractures; and, *B*, the type of assembly used to treat tibial fractures when there is a loose fragment.

Encouraged by these results, it was determined to use this device in other patients. It was also decided that this device might be especially valuable in the treatment of fractures of the tibia when both bones of the leg were involved. Previously it had been found difficult to treat these fractures and especially to obtain early union and good length when the fracture was of the unstable oblique type.

The three-side plate assembly is composed of a main plate and an appositional plate. This device has been tested on a large number of skeletons obtained from the anatomy departments of medical and nursing schools throughout the country. Research on fixation of fractures of the femur still continues and is making considerable headway. Research on fixation of fractures of the tibia has been almost completed, however, and the method now appears to constitute a successful approach with a number of desirable features. This paper is, therefore, mainly concerned with the treatment of fractures of the tibia in patients with fractures of both bones of the leg.

### DESCRIPTION OF PLATES

Four types of main plates have been designed to treat tibial fractures:

*Type 1:* This plate was solid except for the bolt slots and was wider at the extremities than in the middle (Fig. 2). It was the strongest type used in the series, as was definitely shown by tests on dead bone and as was perhaps demonstrated in the male patients who were treated without the use of external support. It was discarded, however, for it seemed to cause more periosteal reaction and greater thickening than did the latest type and it did not always properly fit when used above or below the junction of the lower and middle thirds of the bone.

*Type 2:* This type had notches in the sides. It had no advantages.

*Type 3:* This type was serrated in order that it would better accommodate any irregularities or abnormalities in the tibia. It was not a success, for in several cases it broke in the region of the serrations as a result of walking strain.

*Type 4:* This type has been generally the best. It has fenestrations which seem to reduce reaction and swelling; also the bone and periosteum appear to grow under, over, or around it more easily than they do with other types. It is not wider at the extremities. In Case 12, this plate was used to treat a severely infected compound fracture. Following union of the fragments, the main plate was left in the bone although the lateral appositional plate and the bolts were removed because of persistent sinus formation. The wound healed and has remained healed. In Case 34, the device was used to treat a severe compound fracture with loss of skin. In this case the wound never quite healed, and when the main plate was removed four and a half months after its insertion, it had to be literally dug out of the newly formed bone. A minor mistake was made in not removing the plate earlier. No sign of fracture was seen under the plate, nor was there any sign of bone infection or electrolysis. It seemed that the plate was too near the surface to allow new skin

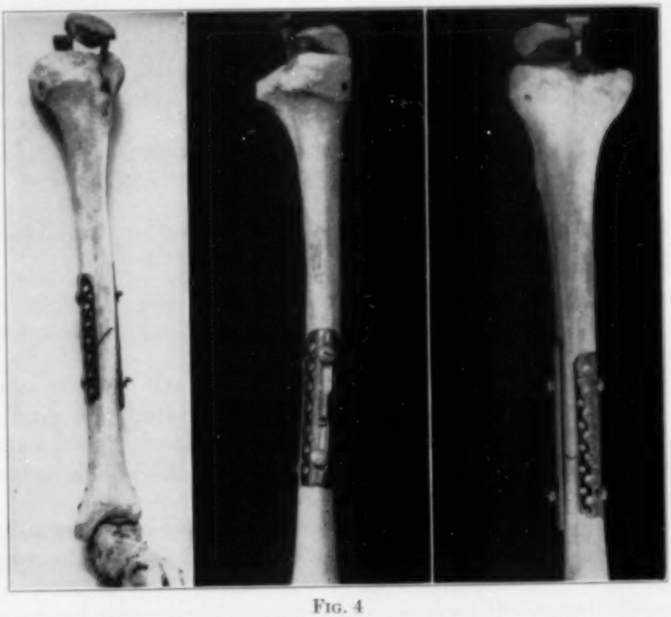

FIG. 4

Photographs showing the plate assembly applied to the tibia.

to grow over it. When this type of assembly is used on narrow ribbon-like tibiae, the gutter of the main plate should be reduced by being compressed in a vise. In our series no tibiae of this type were observed, but occasionally anatomy specimens have been seen.

Since its use in Case 12, Type 4, with minor modifications, has been used in all instances.

At present there are two sizes of femoral plates which are generally used: one for women and small men and a wider one for men with thicker femora. Both types are four inches long. Two longer and larger plates are now available for very large bones. The small plate is made of Vitallium, while the three large sizes are made of stainless steel.

## TREATMENT OF TIBIAL FRACTURES

Since the shape of the tibia varies greatly in individuals of different age, size, and sex, it was found extremely difficult to make a main plate which would be suitable for use in all cases. After many trials in which bones removed from patients by amputation as well as bones obtained from anatomy departments were used, it was decided that the best form of plate was the gutter type. In this device, the surface which is in contact with the anteromedial aspect of the tibia is slightly larger than that which is in contact with the posterior aspect of the tibia. In the latest model, there are fenestrations in the side areas which, it is believed, promote healing and growth of the periosteum (for convenience of manufacturing, these openings are circular). The angle of the plate is slotted like the Eggers plate, and the over-all length is three and one-quarter inches, which allows the plate to be inserted through a reasonably small incision. In conjunction with this plate a three-inch or four-inch Eggers plate is used, this plate being applied to the lateral aspect of the tibia. The Eggers plate should have wide slots which do not bind on the Barr bolts.

In the earlier part of this series, the bolts were placed toward the center of the slots, but later it was discovered that end-fitting of the bolts was more satisfactory. Barr bolts are used for the fixation because they are a standard product easily obtained and because the heads fit very neatly into the slots and can be fastened with beveled washers. In this operation the Eggers plate is generally used in the standard position and the old type of Barr nut is inverted so that it will not turn in the slots of the plate; it is thus easy to apply the two bolts. When the tibia is round or cylindrical in shape, the Eggers plate may be inverted and the new type of nut (hexagonal with nylon inserts) is used.

Although only two bolts are used, the assembly is extremely strong. Because bolts are used instead of screws, there is no chance of threads pulling and the plate assembly giving way when the patient walks. The simple application procedure is illustrated in Figures 3, *A* and 4.

If the fracture is comminuted or if there is a central loose fragment, this simple method is not reliable. A similar but stronger device, requiring a rather longer incision, should be used instead. A long Eggers plate is applied to the lateral surface of the tibia, and after the bolts have been applied but not tightened, screws are inserted at the ends of the plate. This method is shown in Figures 3, *B*, 5-A, and 5-B.

Application of the device to the lower third of the tibia is difficult and should only be attempted after the surgeon is familiar with the proper technique. It is necessary to open the gutter of the main plate and to curve the Vitallium Eggers plate (by means of benders) so that it will fit the condylar expansion of the lower portion of the tibia. Furthermore, the lower bolt would emerge in the posterior half of the lateral surface, that is, at the junction of the anterior two-thirds and posterior one-third of the lateral surface of the tibia, so that the maximum room possible will be allowed for the gliding tendons of the tibialis anterior and extensor muscles. When this device is properly applied, the result is very satisfactory. If, in this region, there is comminution of the fracture or if there are loose fragments, the stronger type of device described in the preceding paragraph cannot be used and therefore an external plaster support should always be applied before weight-bearing is allowed.

The three-side plate assembly is not suitable for fractures of the upper third of the tibia. The author has found Peterson and Reeder's dual slotted plates suitable for these fractures. The plates are screwed on the lateral and anteromedial surfaces, and an above-the-ankle and above-the-knee plaster cast is applied before weight-bearing is allowed.

### *Operative Technique*

The leg is placed on a Brauns frame on the operating table, and an incision four to seven inches in length is made over the medial aspect of the tibia. A smaller incision makes the insertion difficult. A tourniquet is not used.

If the periosteum has been stripped during the injury, the main plate is applied subperiosteally. If the periosteum has not been torn, however, it may be incised along the posteromedial angle of the tibia and the posterior part of the gutter plate slid subperiosteally against the posterior surface of the tibia. Alternatively, and better, the muscle may be gently separated from the posterior surface of the periosteum and the posterior part of the gutter plate applied outside the periosteum, thus leaving the periosteum intact. The anterior and slightly wider part of the plate may lie supraperiosteally or subperiosteally, according to the condition of the periosteum. The present plate may be used interchangeably on either the right or left tibia by being turned, as it were, upside down. (Figure 3, *A* depicts the type of application appropriate for slightly oblique, oblique, or spiral unstable fractures, while Figure 3, *B* shows the type of application which should be used when there is a small central loose fragment.)

The self-aligning property of the plate is one of its great advantages, for it automatically maneuvers the fragments into correct alignment. Furthermore, the insertion of this plate is quicker and easier than the application of a single linear Lane or Eggers type of plate. After the fragments have been correctly aligned, the plate is held by a single bone clamp (Lane clamp or modified Lowman clamp) placed centrally, and holes eleven sixty-fourths of an inch in diameter are drilled through the upper and lower ends of the central slot of the plate. It is important to drill the holes correctly. They should be at right angles to the axis of the shaft and should extend from the posteromedial ridge of the bone to the middle of the lateral surface, as shown in Figure 1. The drill should be enclosed in a steel sleeve which may be held in the hand and which assists the operator in accurately directing the drill at the same time that it protects the soft tissues.

Barr bolts are now inserted, following which the clamp is gently released and the Eggers plate is slipped over the ends of the bolts which fit easily into the holes in the bone. The old-type Eggers nuts are applied, the ridge side being toward the bone, and the bolts are tightened rapidly by means of a screw driver. When the bolts are nearly tight, a final adjustment is made in order to ensure reduction of the fracture. After this, the device is again held with a clamp, and the bolts are fully tightened. The author believes that it is undesirable to make the bolts as tight as possible, as one would in engineering, for it seems most unlikely that living bone can stand such pressures; therefore, only a screw driver is used and the nuts which could be made tighter with a wrench are not so tightened. The author makes the bolts as tight as he can with a screw driver, however. If this part of the operation is not carefully done, a certain amount of movement may occur afterward, allowing the fragments to vibrate and so delaying or preventing bone healing (Case 9, Table I).

In order to ensure absolute fitting of the plate, an assistant should manipulate the foot several times—certainly four times—the bolts being rescrewed each time. These manipulations should be done within five minutes. The ends of the Barr bolts are then cut off with a strong pair of shears, and the wound is gently irrigated with a weak Dettol solution in order to kill any germs which may have entered during the operation. The skin is sutured with a long piece of nylon which is inserted subcuticularly but is twice inter-

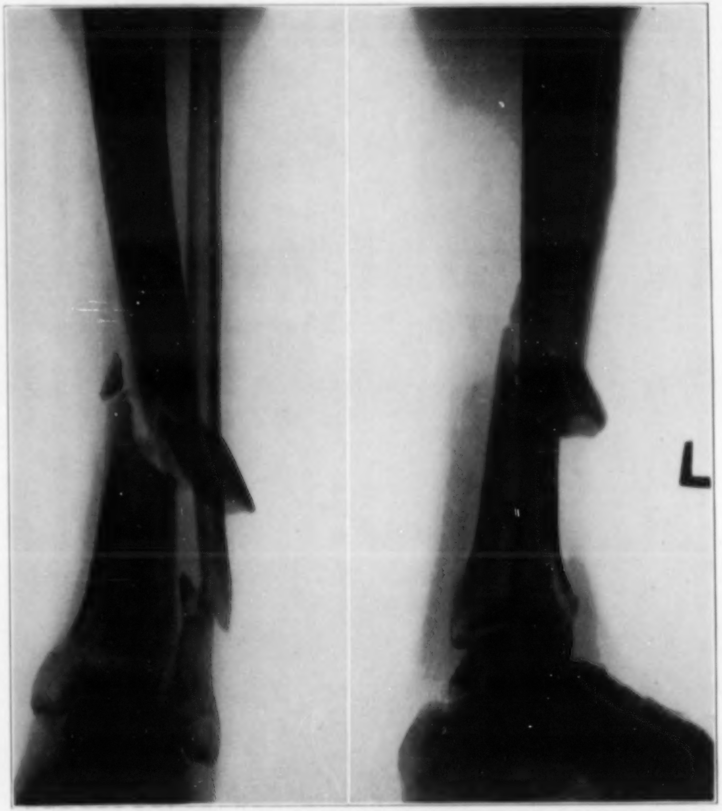

Fig. 5-A

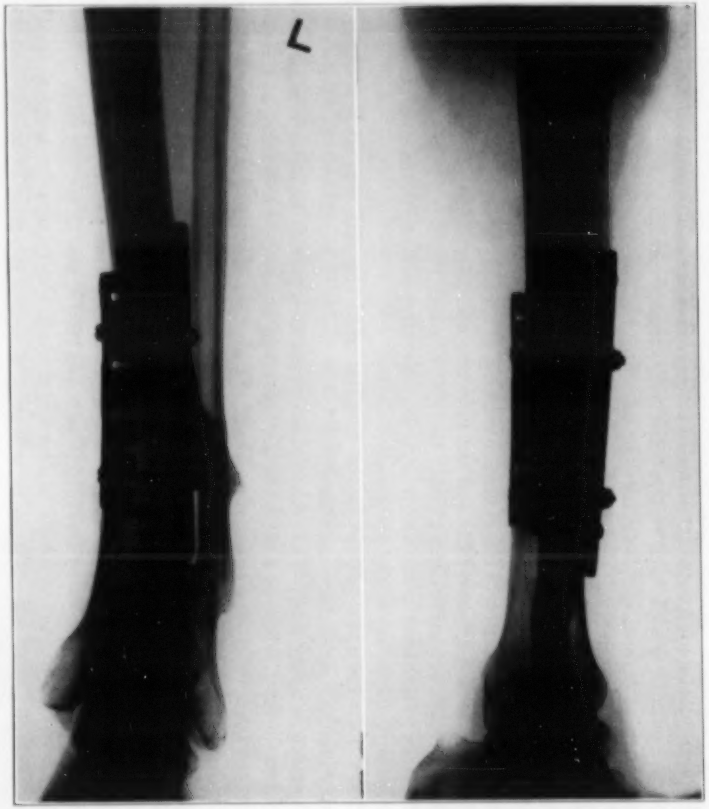

Fig. 5-B

Fig. 5-A: Case 16 (tibial series), a man thirty-eight years old. Preoperative roentgenograms made December 20, 1951. There was a central loose fragment and, therefore, the stronger type of plate assembly was used. The operation was performed three months after the fracture occurred, to treat non-union.

Fig. 5-B: Roentgenograms made February 26, 1954. The result was considered satisfactory.

rupted externally. The limb can now be moved freely. It is dressed with gauze and cotton wool, and the patient is sent back to the ward without any splinting.

A no-touch technique has been used in handling the metal inserts throughout the series of operations, both tibial and femoral.

For those who might wish to try this method, the author offers the following advice which may help to avoid errors and difficulties.

1. The metal assembly should not be touched by the operator's hands.
2. Use of a power drill will facilitate the making of the bolt holes in the correct direction and will eliminate broken drills and the resulting complications.
3. Drill sleeves are useful and protect the soft tissues.
4. Neglect to tighten the bolts at least four times after successive manipulations may result in imperfect holding of the plate assembly.
5. Neglect to keep the patient in the hospital until the skin wound is completely healed may result in secondary infection.
6. Neglect to apply a below-the-knee plaster cast or a plaster or fiberglass gaiter on discharged patients who live at a distance may result in bending or loosening of the plate assembly through accidental slipping or falls and the absence of suitable supervision thereafter. Bone union should be confirmed by roentgenograms before the patient is allowed to participate in outdoor work or games (Cases 4, 9, and 22).
7. If the tips of the toothed metal bone-holding forceps are not covered in some way, the stainless-steel plates may be damaged, with resultant electrolysis (Case 36).
8. The stronger device described previously should be used in cases in which there are loose fragments at the site of fracture (Cases 15, 16, 17, and 21).
9. Fractures in the upper third of the tibial shaft should not be treated by this method, as the plates do not properly fit this portion of the shaft.
10. Treatment of fractures of the lowermost portion of the shaft involves special difficulties in application and should not be attempted until the surgeon is familiar with the proper technique.
11. Grossly atypical tibiae need special care, and plaster casts should always be applied before the patient leaves the hospital.

### *Postoperative Care*

In order to promote good healing, it has been found wise to keep the patient in bed for seven days. Antibiotics are given to prevent infection, penicillin and a sulfonamide usually being considered sufficient in cases of uncomplicated simple fractures and combinations of penicillin, streptomycin, and chloromycetin being used in cases of compound fractures. Foot-drop is likely to occur during the first forty-eight hours and must be assiduously watched for. After seven days the patient is allowed to go short distances in a wheel chair, and on the tenth to the fourteenth day the dressings are taken off and the stitches are carefully removed in sections (it is impossible to withdraw a piece of subcuticular nylon more than three inches long ten days after the operation). If the wound is firmly healed, the patient may get up and start walking. If walking is to commence on a polished hospital floor, the patient's feet should be bare. Many patients like to have the assistance of crutches, sticks, or a walking machine, as the area of fracture may be tender when subjected to full weight-bearing—which nevertheless should be encouraged.

After full ankle movement has been regained, a below-the-knee plaster cast or a plaster gaiter should be applied if the patient is a strong and active man or if the patient, upon discharge, will be outside the range of the surgeon's easy supervision. Patients so protected may resume such light activities as are required in managerial, professional, administrative, or clerical occupations, but outdoor work and all occupations requiring awkward or heavy manual labor should be prohibited until there is roentgenographic evidence of union.

Ladies and elderly persons who are well cared for will do well without any form of external splinting. A knee-bending caliper may be used to prevent accidental strains.

*Case Histories*

All cases in which this method was used are presented in this report (Tables I and II). The case numbers represent the chronological sequence. In all cases but one the fractures involved both bones of the leg; in the one exception (Case 28) only an oblique fracture of the tibia was present. Stable transverse and severely comminuted fractures have not been treated by this method (in these cases a conventional plaster-of-Paris external support was used). The method has also not been considered suitable for children. The youngest patient was a boy of thirteen years (Case 34) who suffered a serious compound fracture when he fell from a tree. The ages of the other patients ranged from nineteen to seventy-one years.

There were fifty-one patients in the total series, thirty-eight with simple fractures and thirteen with compound fractures. In ten of the patients with compound fractures, the three-side plate assembly was inserted at the time of the accident. The remaining three patients in this group had small wounds and the plate assembly was not inserted until after the wound had healed. Twelve of the fifty-one patients had associated severe injuries such as large wounds, head injuries, and fractures of other bones. The shortest period of follow-up in this group was nine months, while the longest was seven and one-half years.

*Very good results:* In this survey, a result was considered *very good* if the length and alignment of the limb was normal, if there was roentgenographic evidence of bone union,

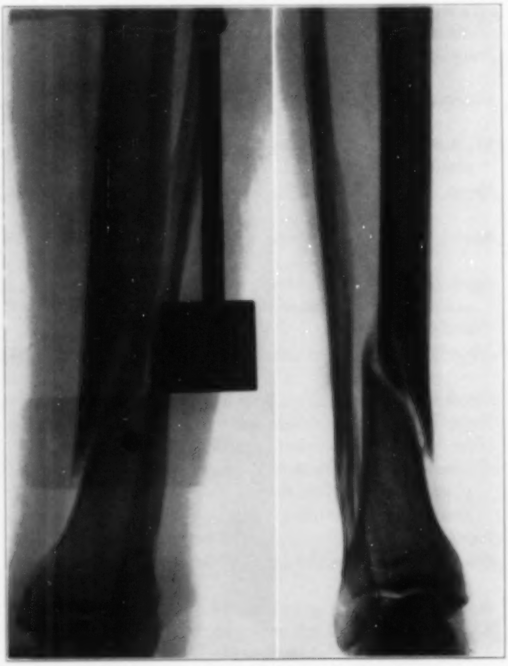

Fig. 6-A

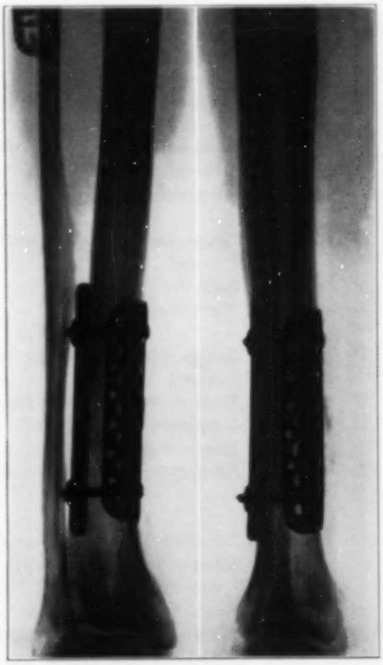

Fig. 6-B

Fig. 6-A: Case 24 (tibial series), a man seventy years old. Roentgenograms made June 7, 1952, a day after the tibial fracture occurred. The plate assembly was applied on June 18, 1952. At this time the patient's blood pressure was 220 systolic 120 diastolic.

Fig. 6-B: Roentgenograms made September 26, 1952, showing evidence of bone union. By fourteen weeks after the operation, the result was considered very good. The patient was alive and well in 1956.

## TABLE I

### TIBIAL FRACTURES

| Case No. | Age and Sex | Type of Fracture | Associated Conditions | Time of Operation after Fracture | Type of Device |
|---|---|---|---|---|---|
| 1 | 25, M | Short oblique, slight comminution, closed | None | 8 days | Ordinary |
| 2 | 26, M | Short oblique, slight comminution, closed | None | 5 days | Ordinary |
| 3 | 70, F | Short oblique, closed | Severe osteo-arthritis, hypertension | 5 days | Ordinary |
| 4 | 29, M | Wedge, moderate comminution, open | Small wound | Same day | Ordinary |
| 5 | 67, F | Long oblique, open | Syringomyelia | Same day | Ordinary |
| 6 | 43, F | Long oblique, closed | Ankylosis of ipsilateral hip | Same day | Ordinary |
| 7 | 47, M | Short oblique, open | Large wound | Same day | Ordinary |
| 8 | 71, M | Long oblique, closed | Pott's fracture | 3 days | Ordinary |
| 9 | 25, M | Short oblique, closed | None | 3 days | Ordinary |
| 10 | 58, F | Short oblique, slight comminution, closed | None | 1 day | Ordinary |
| 11 | 29, M | Short oblique, moderate comminution, closed | None | 3 days | Ordinary |
| 12 | 29, F | Long oblique, open | Severe contamination large wound | Same day | Ordinary |
| 13 | 43, M | Wedge, slight comminution, open | Moderate wound | Same day | Ordinary |
| 14 | 63, F | Long oblique, closed | None | 9 days | Ordinary |
| 15 | 38, M | Wedge, slight comminution, closed | None | 13 days | Extra strong |
| 16 | 38, M | Wedge, moderate comminution, closed | Fracture of other leg | 3 months | Extra strong |
| 17 | 31, M | Wedge, moderate comminution, closed | Fracture of other leg in two places | 13 days | Extra strong |
| 18 | 46, F | Long oblique, closed | None | 5 days | Ordinary and screw |
| 19 | 59, F | Wedge, moderate comminution, closed | None | 7 days | Ordinary and screw |
| 20 | 49, F | Long oblique, slight comminution, open | Open fracture of femur on same side, gross loss of skin and crush injury | 3 months | Ordinary |
| 21 | 56, M | Wedge, slight comminution, closed | None | 2 days | Extra strong |
| 22 | 62, M | Short oblique, closed | Small flesh wound | 5 days | Ordinary |
| 23 | 59, M | Long oblique, closed | None | Same day | Ordinary |
| 24 | 70, M | Long oblique, closed | None | 12 days | Ordinary |
| 25 | 25, M | Short oblique, open | Fractures of fibula in two places, 5th, 6th, 7th, 8th and 9th ribs, clavicle | Same day | Ordinary |
| 26 | 51, M | Long oblique, closed | None | 2 days | Ordinary |
| 27 | 54, F | Short oblique, moderate comminution, closed | Additional fracture 3 inches above | 2 days | Ordinary |
| 28 | 19, M | Short oblique, closed | None | 12 days | Ordinary |
| 29 | 24, M | Short oblique, moderate comminution, closed | Fracture of shaft of femur and many other lacerations | 15 days | Ordinary |
| 30 | 47, M | Long oblique, slight comminution, closed | None | 4 days | Ordinary |
| 31 | 32, M | Long oblique, closed | None | 1 day | Ordinary |

* Below-the-knee plaster casts were usually applied after the patient had walked on bare feet. They were removed one to two months later, following which a gaiter was applied.

## TABLE I

### Tibial Fractures

| Time of Walking with Weight-Bearing after Operation | External Support | Occupation and Time of Return after Operation | Final Results | Length of Follow-up (*Years*) |
|---|---|---|---|---|
| 10 days | None | Laborer, 15 weeks | Good | 7½ |
| 21 days | None | Laborer, 16 weeks | Very good | 3½ |
| Did not walk | Plaster-of-Paris cast | *See case history in text* | Unsatisfactory | 1½ |
| 7 days | None | Retort setter, 49 weeks | Very good | 3½ |
| 32 days | None | Housewife, 13 weeks | Satisfactory | 2¼ |
| 12 days | None | Housewife, 13 weeks | Good | 7 |
| 19 days | None | Engineer, 18 weeks | Very good | 3¼ |
| 20 days | Below-the-knee plaster cast * | Retired | Very good | 2 |
| 19 days | None | Fitter, *see text* | Unsatisfactory | 6½ |
| 24 days | None | Housewife, 17 weeks | Very good | 5½ |
| 21 days | Above-the-knee plaster cast | *See text* | Unsatisfactory | 5 |
| 10 weeks | Below-the-knee plaster cast | Mental-hospital patient | Very good | 6¼ |
| 17 days | Below-the-knee plaster cast | 6 months | Very good | 3¾ |
| 17 weeks | None | Mental-hospital patient | Good | 5½ |
| 14 days | Below-the-knee plaster cast | Merchant, 22 weeks | Satisfactory | ¾ |
| 4 weeks | None | Laborer | Satisfactory | 3½ |
| 4 weeks | Below-the-knee plaster cast | R.A.F., 1 year | Very good | 5 |
| 24 days | Below-the-knee plaster cast | Housewife, 16 weeks | Very good | 4½ |
| 1 month | Below-the-knee plaster cast | Housewife, 16 weeks | Very good | 2¼ |
| About 3 months | None | Housewife, 15 months | Very good | 3 |
| 12 days | Below-the-knee plaster cast | Riding instructor, 3 months | Very good | 4¾ |
| 3 weeks | Below-the-knee plaster cast | Laborer, 5 months | Very good | 4½ |
| 3 weeks | Below-the-knee plaster cast | Manager, 10 weeks | Very good | 3½ |
| 21 days | Below-the-knee plaster cast | Odd jobs, 14 weeks | Very good | 3½ |
| 34 days | Below-the-knee plaster cast | Laborer, 26 weeks | Very good | 4¼ |
| 3 weeks | Gaiter | Factory worker, 23 weeks | Satisfactory | 3½ |
| 5 weeks | Below-the-knee plaster cast | Housewife, 15 weeks | Very good | 3½ |
| 6 weeks | Below-the-knee plaster cast | Bricklayer, 11 weeks | Very good | 3¾ |
| 3 months | Caliper | Farmhand, 39 weeks | Very good | 1¼ |
| 10 days | Below-the-knee plaster cast | Farmer, 12 weeks | Very good | 3½ |
| 16 days | Below-the-knee plaster cast | City alderman, 15 weeks | Very good | 3 |

TABLE I

TIBIAL FRACTURES *(Continued)*

| Case No. | Age and Sex | Type of Fracture | Associated Conditions | Time of Operation after Fracture | Type of Device |
|---|---|---|---|---|---|
| 32 | 30, M | Severe fracture with 4 large fragments, open | Wound 3 inches long | Same day | Ordinary |
| 33 | 60, M | Short oblique, closed | None | 7 days | Ordinary |
| 34 | 13, M | Long oblique, open | Severe shock | Same day | Ordinary |
| 35 | 33, F | Large central loose fragment with comminution, open | Severe shock | Same day | Ordinary with two screws in upper fracture |
| 36 | 18, M | Long oblique, marked comminution, closed | None | Same day | Ordinary |
| 37 | 34, M | Long oblique, closed | None | 9 days | Ordinary |
| 38 | 60, M | Long oblique, open | None | Same day | Ordinary |
| 39 | 22, M | Short oblique, closed | None | 16 days | Ordinary |
| 40 | 20, M | Wedge, closed | None | 6 days | Ordinary |
| 41 | 33, F | Osteotomy step-cut, closed | None |  | Ordinary |
| 42 | 37, M | Upper one-third, comminution, closed | None | 1 day | Extra strong |
| 43 | 29, M | Short oblique with vertical crack, closed | None | 21 days | Ordinary |
| 44 | 37, M | Short oblique, comminution open | None | 3 months | Ordinary |
| 45 | 43, M | Short oblique, closed | None | 12 days | Ordinary |
| 46 | 19, M | Short oblique, open | None | Same day | Ordinary |
| 47 | 67, M | Long oblique, closed | None | 7 days | Ordinary |
| 48 | 24, M | Short oblique, some comminution, closed | None | 4 days | Ordinary |
| 49 | 66, F | Long oblique, slight comminution, closed | None | 6 days | Ordinary |
| 50 | 54, M | Long oblique, closed | None | Same day | Ordinary |
| 51 | 49, F | Long oblique, closed | None | 9 days | Long plate |

if the range of ankle and knee movement was the same as before the accident, if there were no complications, and if the patient could return to work in a reasonable length of time (Figs. 6-A and 6-B). Thirty-seven patients in this series had *very good* results.

*Good results:* A *good* result was the same as a *very good* result except that there was skin reaction and staining due to electrolysis from the stainless steel; in these cases the plates were removed after the bone fragments had united. Four patients qualified for this rating.

*Satisfactory results:* A *satisfactory* result was deemed to have been obtained if there was normal length, roentgenographic evidence of good union, freedom from skin complications, normal ankle movement, and only slight loss of normal alignment (Figs. 5-A and 5-B). These criteria are comparable to those for a good result following conservative treatment. In seven patients in this series the result was satisfactory.

*Unsatisfactory results:* A result was considered a failure if there was clinical evidence of non-union, that is, if there was movement at the site of fracture. Unsatisfactory results occurred in Cases 3, 9, and 11. Descriptions of these cases follow:

CASE 3. The patient was seventy years old. A bolt head pulled through the main plate, so that the apparatus did not hold properly. A good result by any form of treatment was unlikely in this case, however, for the patient had a severe cross-legged deformity, bilateral osteo-arthritic deformities of the knees and hips, and cardiovascular disease.

TABLE I

TIBIAL FRACTURES *(Continued)*

| Time of Walking with Weight-Bearing after Operation | External Support | Occupation and Time of Return after Operation | Final Results | Length of Follow-up (*Years*) |
|---|---|---|---|---|
| 1 month | Full plaster cast | Boiler fireman, 20 weeks | Very good | 4 |
| 4 weeks | Below-the-knee plaster cast | Civil servant, 8 weeks | Satisfactory | 3¼ |
| 1 month | None | Schoolboy, 6 months | Very good | 3¼ |
| 16 days | Full plaster cast | Housewife, 6 months | Satisfactory | 3¼ |
| 20 days | Below-the-knee plaster cast | British Army, 5 months | Satisfactory | 3¼ |
| 16 days | Below-the-knee plaster cast | Fire service, 7 months | Very good | 2¾ |
| 1 month | Below-the-knee plaster cast | Headwaiter in restaurant R.R. car, 6 months | Very good | 2 |
| 13 days | Below-the-knee plaster cast | Locomotive fireman, 16 weeks | Very good | 2½ |
| 17 days | Below-the-knee plaster cast | Agricultural engineer, 18 weeks | Very good | 1¼ |
| 14 days | Below-the-knee plaster cast | Factory worker, 16 weeks | Very good | 1¾ |
| 2 months | Above-the-ankle and above-the-knee plaster cast | Clerical worker, 6 months | Very good | 2 |
| 15 days | Plaster gaiter | Driver and loader of motor truck, 26 weeks | Very good | 2¼ |
| 1 month | Caliper |  | Satisfactory | 2 |
| 15 days | Caliper | Farmer, 5 months | Very good | 2¼ |
| 14 days | Below-the-knee plaster cast | R.A.F., 13 weeks | Very good | 2½ |
| 16 days | Plaster gaiter | Clerical worker, 11 weeks | Very good | 2 |
| 1 month | Gaiter and caliper | Mechanic, 5 months | Very good | 1½ |
| 16 days | Plaster gaiter and caliper | Housewife, 23 weeks | Good | 1¾ |
| 14 days | Below-the-knee plaster cast | Engineer, 6 months | Very good | 1 |
| 16 days | Caliper | Housewife, 16 weeks | Very good | 2 |

CASE 9. The patient was twenty-five years old. His initial postoperative course was good but complications developed later due to insufficient supervision. When he was discharged, to return to his home town twelve miles away, he was walking well and had no plaster support. The complications that subsequently developed may have been the result of his being too active so that the plate assembly was loosened by vibration, or they may have been the result of marked electrolysis. The initial complication was the development of a hematoma which unfortunately was not recognized and, therefore, was allowed to ulcerate, discharge, and become secondarily infected. When the plate assembly was removed six months later, marked corrosion and rusting of one of the stainless-steel bolts was visible. The rusted bolt moved the compass needle but the plate did not.

The patient's ill luck continued, for while he was still restricted to sedentary work and before union was obtained, he fell on the ice and refractured his leg. The fragments were still not united after several months of conservative treatment. Beck's bone-drilling operation demonstrated intense eburnation of the bone and caused a portion of the bone to die and to be sequestrated. After considerable further treatment by plaster supports, the fragments appeared clinically to have united in a position of slight backward bowing. When last seen in December 1956, the patient reported that the leg was functioning satisfactorily and that he had worked regularly since July 1953.

All the trouble could have been prevented had the patient been kept under supervision at the hospital or had a below-the-knee plaster cast been applied. As a result of this unfortunate experience, below-the-knee casts were provided for all subsequent patients who went any distance from the hospital after discharge and greater efforts were made to supervise these patients.

Case 11. The case of this twenty-nine-year-old man was very unusual. He had closed but comminuted fractures of both the tibia and fibula at the junction of the lower and middle thirds. On July 27, 1950, a Type 1 plate was applied and some of the comminuted bone was removed, a step which is now believed to have been an error.

The wound appeared to heal well. An above-the-knee plaster cast was applied because of the loss of bone fragments. Roentgenograms made September 20, 1950, showed good bone union and the cast was removed. On October 10, 1950, the patient, who was very active at that time, fell off a stepladder and cracked the bone at the site of the old fracture, slightly bending the stainless-steel plate. A plaster cast was again applied and the patient did well. On November 1, 1950, the cast was removed and the patient was given permission to do light work. On January 17, 1951, he fell again, after which he complained of slight pain. He was seen again on April 4, 1951. His leg was swollen and the skin over the old fracture site was red, but he said he was walking seven miles to and seven miles back from his job as well as doing a full day's work. When he was seen again in December 1951, the roentgenograms suggested the presence of non-union. It appears now that he had a very low threshold of pain and an unusual desire to work, but this was not fully realized at the time. The patient temporarily disappeared from the district.

When he was seen again in March 1954, he insisted he could work regularly driving public passenger buses. His leg at that time showed considerable bone swelling. At the next examination in November 1954, he reported that he was still driving a bus regularly and that he was playing football. Roentgenograms showed non-union and fracture of the plate. The plate was removed and it was found that there was no bone union at all. The plate itself was broken into five pieces (apparently as a result of metal fatigue), a finding which constitutes an undesired testimonial to the holding power of the plate.

The fragment ends (the line of fracture was now transverse) were freshened, the medullary canal was reamed, and a full-length plaster cast was applied. Good alignment and healing have since been obtained.

It has seemed appropriate to present a detailed description of the three cases in which unsatisfactory results were obtained. A single case each will be presented to illustrate a satisfactory, a good, and a very good result. A case in which a very good result was obtained under adverse circumstances will also be described.

### *Satisfactory Result*

Case 33. A sixty-year-old man had suffered short oblique fractures in the lower thirds of both leg bones as a result of a road accident. He was received from another hospital where a temporary plaster cast had been applied with the fragments in poor position. On May 28, 1953, fixation of the tibial fracture by the three-side plate assembly was attempted, but it was found impossible to obtain absolute reduction without making an undesirably deep dissection. The fragments were therefore fixed in a position of slight anterior bowing but correct anteroposterior alignment. The wound healed soundly in fourteen days, and after being given a course of exercises to strengthen the ankle, the patient was discharged, his leg being protected by a below-the-knee fiberglass cylinder splint. He returned to his office job eight weeks after the operation and has continued working since then.

The external support was removed three months after the operation, but the patient continued to have swelling of the leg and dull pain. Roentgenographic evidence of union was not present until nearly six months after the operation. A year later slight swelling and dull pain were still present, but there was a full range of movement in the ankle.

On September 19, 1955, the plate assembly was removed and doubtful evidence of electrolysis was observed. When last seen September 7, 1956, the patient appeared well.

### *Good Result*

Case 14. The patient was a sixty-three-year-old woman who was under hospital care for chronic mental illness. On July 10, 1951, she sustained oblique fractures in the lower middle portions of both bones of the right leg. Fixation by the three-side plate assembly was done on July 12, 1951, and the patient returned to the mental hospital a few days later.

The wound was healed by July 27. At that time the patient needed no nursing apparatus and was allowed to sit up in a chair as much as was considered compatible with her mental condition. Roentgenograms showed complete union seventeen weeks after the operation.

On November 24, 1952, she complained of some pain in the region of the plate assembly and the skin in this area showed some tendency to become spotted and to break down. The skin condition healed a week or two later.

On December 12, 1953, brown discoloration of the skin in the area of the scar was observed and the occurrence of electrolysis was confirmed by removal of the plate assembly. Sound healing of the skin was present by February 13, 1954. The wound remained healed thereafter, but when the patient was last seen January 5, 1957, the brown discoloration of the skin was still present.

### *Very Good Result*

CASE 30. A man forty-seven years old was kicked by a cow, suffering a closed oblique fracture in the lower middle portion of the right tibia and a similar fracture in the neck of the fibula. The plating operation was performed four days later on May 7, 1953, and the wound healed by May 21. The patient was able to walk on the leg ten days after the operation. A below-the-knee plaster cast was applied and the patient was discharged with permission to supervise the work on his farm but not to do any physical labor.

On June 12, 1953, five weeks after the operation, a below-the-knee fiberglass cast was substituted for the plaster cast and shortly thereafter the patient was observed working, contrary to instructions—throwing out cattle feed from a trailer.

Twelve weeks after the operation there was roentgenographic evidence of good callus formation and the patient was given permission to do active farming. When he was seen on December 4, 1953, there was good bone union and a full range of ankle movement. The patient was last seen January 11, 1957. The leg had given him no trouble and was in excellent condition.

### *Very Good Result under Adverse Circumstances*

CASE 32. A thirty-year-old man was in a motor accident, sustaining open fractures of the middle portions of the tibia and fibula in two places.

Operative treatment was carried out the evening of the accident. The accident wound, which was three inches long, was prolonged to make the incision. The tibia was found to be in four pieces, none of these pieces being quite detached from the muscle or periosteum. The fractures were complete and there was marked displacement of the fragments.

Because of the skin injury, the wound took over a month to heal. The patient was given no external support until five weeks after the operation, when an above-the-knee walking plaster cast was applied. He was then sent to his home in a distant town.

Fourteen weeks after the operation, the cast was removed. The wound had completely healed and roentgenograms showed that bone union was progressing. The patient was allowed to go on a month's holiday. He returned to his job as a boiler fireman twenty weeks after the accident and has had no further trouble. He was last seen August 22, 1957.

### *Complications*

*Imperfect anatomical alignment:* In only two patients in this series (Cases 15 and 33) was the plate assembly applied with the bone fragments out of perfect alignment. One of these patients (Case 15) was first treated conservatively, and the other (Case 33) was received from another hospital where a plaster cast had been applied with the fragments in poor position. In both cases the slight malalignment was probably due to small bone fragments lying between the central surfaces of the main fragments. A more radical exposure of the fracture would probably have obviated the trouble.

*Movement of fragments:* Slight movement of the fragments occurred during healing in five patients. In one of these patients (Case 5) the plate assembly did not fit properly, the appositional plate being too short; and in two (Cases 11 and 26) the plate assembly became bent as a result of falls downstairs. The case histories of the other two patients (Cases 3 and 9) have already been given.

*Delayed union:* As is well known, the length of time required for union of fractures of the tibial shaft is variable. It seems generally agreed, however, that early repair of fractures of this bone is unlikely, and in this review six months was considered as the normal time required for union. In light of the observations and research of Urist, Mazet, and McLean, this period appears to set a reasonably high standard. On this basis delayed healing was present in seven cases (Cases 3, 4, 17, 29, 35, 42, and 44).

CASE 4. The delayed union in this case was probably due to the patient's being allowed to return to outdoor activity too early. Also the plate assembly was probably prevented from holding firmly by the presence of a central loose fragment. The stronger type of device should have been used.

CASE 17. This was an unusual case in that both bones in both legs were broken. The fracture in the lower half of the right tibia was treated by the three-side plate assembly. The fractures in the cancellous bone of the left leg were treated by the application of a full-length plaster cast. The right limb, protected by a below-the-knee plaster cast, bore the main portion of the patient's weight.

CASE 29. This patient also had a fracture of the femoral shaft which was treated by conservative means. The delay in union was probably caused by the small loose fragment which was removed from the site of the tibial fracture at operation.

TABLE II

| | Healing of Soft-Tissue Operative Wound | | | | | Bone Healing | | |
|---|---|---|---|---|---|---|---|---|
| | Normal (Under 14 days) | Delayed Healing Due Original Condition | Delayed Healing Due Hema-toma | Sepsis after Operative-Wound Healing | Skin Eruption Due to Electro-lysis | Normal (Under 26 Weeks) | Delayed Union | Non-Union While under Author's Treatment |
| Tibial | | | | | | | | |
| Simple (38) | 30 | 1 | 7 | 1 | 4 | 32 | 4 | 2 |
| Compound (13) | 8 | 5 | | 2 | | 10 | 3 | |
| Femoral | | | | | | | | |
| Simple (11) | 11 | | | | | 11 | | |
| Compound (5) | 5 | | | 1 | | 4 | 1 | |

CASE 44. Non-union was clinically evident after three months of treatment by means of a plaster cast. The three-side plate assembly was then applied. A dead comminuted fragment was not removed, but roentgenograms made three months later indicated that it was absorbed. The plate fixation was not considered technically satisfactory.

*Traumatic necrosis of the skin:* This occurred in a patient (Case 34) in whom there was a primary skin loss due to the original injury. The bone healed well and early.

*Electrolysis:* In Cases 1, 6, 14, and 36, there was evidence of electrolysis. In Cases 6 and 14, the electrolysis appeared to be caused by a stainless-steel bolt. In Case 36 it was caused by the main plate itself, the polished surfaces of which had apparently been injured by a Lane's bone-holding forceps. In these three cases, the electrolytic effects were almost completely confined to the soft tissues and the condition was immediately relieved by removal of the stainless steel. In Case 1 electrolytic changes developed very gradually and the plate was removed in February 1955. After Case 15, Vitallium bolts were used in all cases.

### *Further Comments*

In thirteen cases (Cases 5, 7, 12, 13, 16, 20, 25, 29, 32, 34, 38, 46, and 53), satisfactory or very good results were obtained under adverse circumstances. These cases must, therefore, be considered as evidence in favor of this method of plating (Figs. 5-A and 5-B).

In three cases (Cases 16, 20, and 44) the plate assembly was applied following failure of conservative methods used over periods of three months.

Twenty-four additional patients with tibial fractures have been treated by the author since this paper was originally prepared. These patients were seen too recently to be included in this series. One of these patients had multiple injuries including a severe open double fracture of the tibia. This patient died of shock twelve hours after the operation, a result which cannot be attributed to the method of plating. Another patient suffering from mild diabetes mellitus with an open fracture had an infection and the operative wound did not heal until the whole plate assembly had been removed, but the result is otherwise good. In the other cases, the results either are or are likely to be very good.

In no patient with a recent closed fracture did the surgical wound become infected, but in Case 68, a woman fifty-one years old, who had clinical non-union after three months in plaster of Paris, there was a mild infection of a hematoma. The wound did not heal completely until the plate assembly was removed. Good union of the fractures was obtained in three months in anatomical position.

## TREATMENT OF FEMORAL FRACTURES

### *Operative Technique*

The insertion of the appliance is difficult in the well developed, muscular thigh of the athlete. In the atrophied limb of an elderly patient, however, it ordinarily is not difficult.

Blood for transfusion should always be available. The operation should not be attempted unless at least two sizes of the main plate and of the Eggers appositional plate are available. At present the author uses four sizes. There must also be available three special wrenches and four sizes of Barr bolts with nylon hexagonal nuts and with washers to be used at the heads of the bolts. The sizes of the Barr bolts are one and one-half inches, two inches, two and one-half inches, and three inches. The smallest size is used in women with small bones, while the largest size is used to treat supracondylar fractures in men in whom it may be necessary to bend the Eggers appositional plate. The main plate should not be adjusted. Wenger-type Vitallium bolts may also be used; they are as easy to apply but require the use of lock nuts as an extra precaution.

The special wrenches consist of a box wrench fitted on a curved handle (to be used for the first application of the nuts), a straight box wrench, and an open-ended wrench for final tightening of the nuts. All of these wrenches fit the Barr nylon insert hexagonal nut or the type of bolt being used.

The limb is placed on a Brauns type of splint. An anterolateral incision is used for fractures of the lower third of the femur, and an anterior incision is used for mid-shaft fractures. These plates must not be used to treat fractures above the mid-shaft; in this region the Küntscher nail is especially efficacious.

Drills about six to eight inches in length, for inserting both the bolts and the screws, must be available; and drill sleeves three inches long are essential in order to obtain correct drilling of the holes. Hand drills should not be used unless there is a power failure. When drilling the bone, it is advisable to place the blade of a large retractor on the medial side of the bone in order to avoid injury to the muscles and vessels by the sudden emergence of the drill.

After the bone fragments have been maneuvered into correct anatomical position, the main plate is applied and held in position by two screws. The screws may be placed centrally and the bolts fitted at the distal ends of the plate. In the muscular thigh this may be very difficult, and, therefore, in such a case the alternate method in which the bolts are placed more centrally is recommended (Figs. 3, *F*, 7-A, 7-B, and 7-C).

The fitting of the bolts is made easy by the primary fixation of the plate in good position with screws. The appositional Eggers plate is fitted with the gutter side against the bone, that is, the reverse way from that used to obtain "contact splintage." The bolts are tightened as much as possible by means of a screw driver and are then given a further half turn with a wrench. On no account should the nuts be made more than finger tight. On the other hand, the leverage on the femur is so great that proper tightening is most important.

Manipulation of the bone should be done as it is in the tibial operation, and use of the same general precautions and method of skin suturing is advised. Catgut for the muscles and fascia is preferred. After the femoral operation, a sponge count must be made, as is customary in abdominal surgery.

The postoperative care is similar to that given following the tibial operation, except that knee-flexion exercises are started on the third day. If the plates have been properly applied, as determined by subsequent roentgenographic study, walking on bare feet without cast protection may be commenced as soon as the skin wound is soundly healed.

A corset-top, non-weight-bearing caliper should be used during all outdoor activities until roentgenograms confirm the presence of bone union. A knee-bending caliper with the usual type of lock may be used to make possible early activities if the patient has pressing reasons for returning to his business occupation. Patients should be warned against walking on ice or slippery clay.

### *Results*

Femoral fractures were not routinely treated by the three-side method, which was used only in patients in whom malalignment and shortening could not be overcome by traction and in patients in whom there appeared to be muscle tissue between the fragments. There were sixteen patients in this series. The longest period of follow-up was eight years and the shortest was one and three-quarter years.

The Küntscher-nailing operation was done concurrently in patients in whom there were fractures of the middle and upper portions of the shaft or in whom a central loose intact fragment was present.

The three-side-plate operation is generally no harder to perform than Küntscher nailing. In patients with well developed muscular thighs it may be somewhat difficult, but in elderly persons it is usually easy and seems to cause less shock than do other methods.

A survey of the results (Tables II and III) shows that the method was very successful (Figs. 7-A, 7-B, and 7-C). The first unsatisfactory result that occurred (Case 2) was due to failure to apply the plate assembly correctly because of lack of experience. The femoral plates were a little too small for the bone of the patient who was a large man; larger ones are now used for such patients.

The other patient in whom the result was unsatisfactory (Case 15) was a woman aged seventy-seven years. In this case the bone was refractured above the plate assembly. The new fracture was treated conservatively. It is not known whether this fracture was due to a crack which was not seen either at operation or in the roentgenogram or whether it was due to the bone being unusually brittle. At the conclusion of the treatment there was some malalignment and shortening and the result had to be classified as *unsatisfactory*.

In no patient with an open fracture was the plate inserted until the wound had healed. One patient who had been run over by a bus and had suffered loss of skin down the medial side of the leg and open fractures of both bones of the leg (Case 20 in the tibial series) as well as an open fracture of the femur (Case 6 in this series) had a recrudescence of sepsis after the operative wound had healed. The plate was removed a year later, after which there was no further trouble.

In two patients (Cases 11 and 13) there was slackening of the nuts due to use of a new type of washer and to the use of nuts without nylon locking inserts. Another technical difficulty was incorrect centering of the appositional plate (Case 5); in this case a satisfactory result was produced. Except in Case 5, the results which were only satisfactory rather than good were attributable to damage caused by the trauma of the accident and were not due to errors in operative treatment (Cases 6, 11, and 16).

In the eight patients treated since this series was completed, there have been no complications.

## CASE HISTORIES

### *Unsatisfactory Result*

CASE 2. A farmer, twenty-one years old, suffered an open fracture of the right femur. Following healing of the small wound, roentgenograms showed wide separation of the fragments between which there was apparently soft tissue. An operation was performed on July 13, 1950, and the presence of considerable muscle tissue between the fragments was confirmed. Original-type Vitallium plates were applied. Unfortunately, the appositional plate was too short, and about a month after the operation it slipped into the medullary canal at the upper end of the shaft as the result of a previously unnoticed loose fragment on the medial side. Only two bolts had been used and the upper end of the appliance became unstable, allowing a hinge action around the upper bolt. In August 1950, a walking caliper with a plaster socket was applied, and good position of the fragments was maintained thereafter. Union was slow, however, and the socket was removed too early (March 1951) with the result that some anterior bowing developed in the region of the callus; this could not be corrected. A year later there was firm bone union and the patient returned to his farm work. By Octo-

Fig. 7-A: Case 9 (femoral series), a woman seventy-four years old. Roentgenograms made November 27, 1952, a day after the accident.

Fig. 7-B: Roentgenograms made December 16, 1952, seven days after the operation. By January 17, 1953, she was learning to walk again with full weight-bearing, and by February 6, she could walk nicely. When she was discharged from the hospital on March 3, 1953, she was walking with full confidence.

Fig. 7-C: Roentgenograms made April 28, 1955. This result was considered very good.

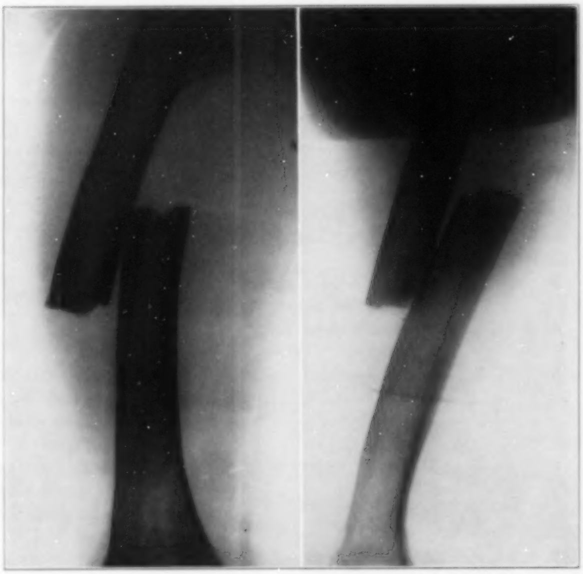

Fig. 7-A

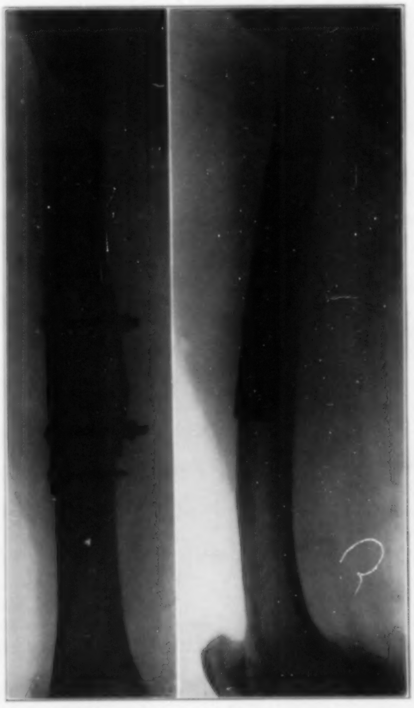

Fig. 7-B

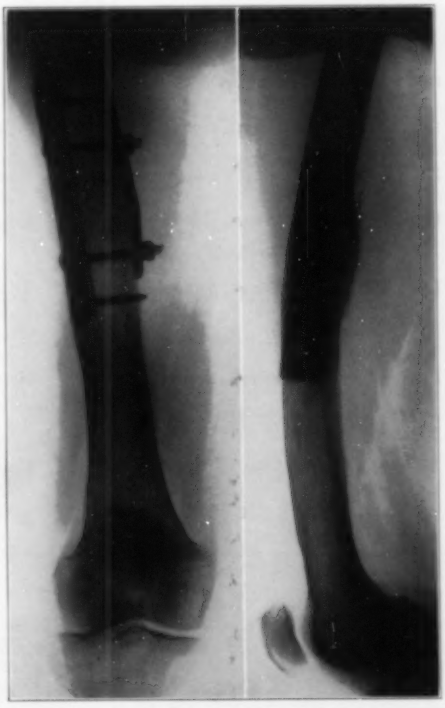

Fig. 7-C

## TABLE III

### Femoral Fractures

| Case No. | Age and Sex | Type of Fracture | Associated Conditions | Time of Operation after Fracture | Time of Walking with Weight-Bearing after Operation |
|---|---|---|---|---|---|
| 1 | 56, M | Lower one-third, oblique, closed | None | 9 days | 5 weeks |
| 2 | 21, M | Lower one-third, transverse with loose fragments, open | None | 14 days | 2 months |
| 3 | 20, M | Lower one-third, almost transverse, closed | None | 5 days | 4 weeks |
| 4 | 41, M | Mid-shaft, short oblique, closed | None | 6 days | 2 weeks |
| 5 | 27, M | Lower one-third, transverse with loose fragments, open | Concussion, fracture of pelvis, wide separation of symphysis pubis, loss of end of finger | 1 month | 3 weeks |
| 6 | 49, F | Mid-shaft, tranverse, open | Compound fractures in both bones of leg, severe skin loss, and soft-tissue damage | 2 months | About 3 months |
| 7 | 84, F | Mid-shaft, transverse, closed | None | 7 days | |
| 8 | 16, M | Mid-shaft, oblique with fragmentation, closed | Bruising of thigh | 10 days | 3 weeks |
| 9 | 74, F | Mid-shaft, almost transverse, closed | None | 13 days | 6 weeks |
| 10 | 81, F | Lower one-third, oblique, closed | None | 2 days | 4 weeks |
| 11 | 41, M | Mid-shaft, transverse, open | Fractured patella | 4 weeks | 3 weeks |
| 12 | 57, F | Mid-shaft, step-type, closed | Intertrochanteric fracture of ipsilateral femur | 7 days | 3½ months |
| 13 | 24, M | Mid-shaft, short oblique, closed | Concussion | 8 weeks | 3 weeks |
| 14 | 27, M | Mid-shaft, transverse, open | Trimalleolar Pott's fracture, fracture of calcaneus, navicular, and patella in ipsilateral leg | 18 days | 4 weeks |
| 15 | 77, F | Mid-shaft, step-type, closed | None | 6 days | 8 weeks |
| 16 | 24, M | Mid-shaft, transverse with loose fragment, closed | Concussion, fracture upper third of tibia, large soft-tissue wound below the knee | 7 months | 4 weeks |

ber of that year he was able to do heavy labor. At the conclusion of treatment there was a shortening of one and one-quarter inches and a serious loss of knee movement, the range being from full extension to 20 degrees of flexion.

Nevertheless, despite this unsatisfactory result (Fig. 9), when the patient was last seen in January 1957, he reported that he was able to do all kinds of heavy farm work and that he had no pain or weakness.

TABLE III

FEMORAL FRACTURES

| External Support | Occupation and Time of Return after Operation | Length of Follow-up (*Years*) | Complications | Final Result |
|---|---|---|---|---|
| None | Gas fitter, 6 months | 8 | None | Very good |
| Caliper with thick plaster socket | Farmer, 1⅔ years | 6½ | Plate assembly improperly applied, appositional plate too short | Unsatisfactory |
| None | R.A.F., 3 months | 5¾ | None | Very good |
| Caliper | Farmer, 6 months | 5 | None | Very good |
| Caliper with plaster thigh socket | Locomotive fireman, 10 months | 5 | Plate moved after operation | Satisfactory |
| None | Housewife, 2 years | 4½ | Residual sepsis after wound healing, plate removed 13 months after operation | Satisfactory |
| | | | Uterine hemorrhage | Died of uterine hemorrhage 3 weeks after operation |
| None | Farmhand, 20 weeks | 4½ | None | Very good |
| None | Retired | 4 | None | Very good |
| None | Retired | 2 | None | Very good |
| Corset-top caliper | Ambulance driver, 7 months | 3½ | Adhesion of muscle in thigh, bolts slackened | Satisfactory |
| None | Retired | 3 | None | Very good |
| Corset-top caliper | Plumber, 9 months | 2¾ | New-type bolts slackened and had to be tightened up | Very good |
| Below-the-knee plaster for leg fractures, no femoral support | Miner | 2¼ | None | Very good |
| None | Retired | 2¼ | Fell 10 weeks after operation and refractured femur above site of plating | Unsatisfactory |
| Caliper | Farmer, 13 months | 1¾ | Postoperative hematoma | Satisfactory |

### *Satisfactory Result*

CASE 5. A railway locomotive fireman, twenty-seven years old, while riding a motor cycle in the fog on December 17, 1951, was seriously injured in a collision. He suffered a concussion, loss of the tip of the third finger, fracture of the pelvis with wide separation of the pubis, and open fracture of the shaft of the right femur. The femoral fracture was cleaned and the limb was placed in traction that same day. On December 24, the widely separated pubis was sutured with Mersilene thread. A large pelvic hematoma was found. On

January 17, 1952, the thigh wound being healed, the mid-shaft fracture was fixed by the three-side plate assembly. The wound healed well and the patient was allowed up within three weeks of the operation. In the middle of March, while walking, the patient experienced a clicking sensation in the thigh. Clinical and roentgenographic examination revealed slight movement at the upper end of the plate. A walking caliper and a plaster thigh socket were immediately applied. This mishap was caused by the same factor that had caused the difficulty in Case 2: there was a small, previously unnoticed loose fragment on the medial side of the shaft. In this case, however, the fragments remained in good position until full union was present (June 1952). In October 1952, the patient was able to return to his usual occupation, although he did not have a full range of knee flexion. When he was last seen in January 1957, the range of movement in his knee was from full extension to 105 degrees of flexion. He was able to do all the work required by his job and reported that he had consistently been able to do so since he returned to work in 1952.

### *Very Good Result*

CASE 4. A man, forty-one years old, who owned a small farm which he ordinarily ran singlehanded, suffered a closed oblique fracture of the mid-shaft of the left femur on November 9, 1951. Six days later, on November 15, the fragments were aligned in correct anatomical position and the three-side plate assembly was applied. A stainless-steel main plate was inserted first, two Vitallium screws being placed at the extremities of the slots to hold the plate in position. The stainless-steel bolts and appositional plate were then fitted and secured, each bolt being placed half way from the center of the main plate. By November 29, 1951, the operative wound had healed, and on November 30, the patient was allowed to stand and walk slowly on bare feet using crutches. He was fitted with a walking caliper and allowed to go home for Christmas. He was visited at his farm on January 21, 1952, and was found doing manual labor, contrary to instructions—feeding stock on a muddy field. On March 21, 1952, twenty-one weeks after the operation, roentgenograms showed good bone union and it was found that the range of knee movement was from full extension to 90 degrees of flexion. On May 30, 1952, he was given permission to return to full activity. When visited on January 4, 1957, he reported that he had been working regularly since June 1952. He had full movement in all joints and the left limb was indistinguishable from the unbroken right limb.

## DISCUSSION

In this series difficulties arose from lack of sufficient experience with the technique. Use of an appositional plate that was too short, failure to center the plate correctly over the fracture, and use of unsuitable bolts or nuts were among the causes of trouble.

It is now known that if the plate assembly is not perfectly applied, trouble may be avoided by prohibiting weight-bearing, by using a plaster-of-Paris cast or splints, and by arranging the same postoperative regimen as is customary following single-plate operations. An excellent result may then be expected and further operations may be avoided.

Even when the plate assembly is imperfectly applied, shearing and whipping stresses are likely to be less than they would be if a single plate were used. When a single plate is used, whipping stress, that is, distraction of the bone fragments, occurs on the side of the shaft opposite the plate. This distraction is caused by spring in the metal when the limb is subjected to side stress.

Observations made in this series indicate that in three-side fixation soft-tissue healing is quite normal and that the general thickening seen at the site of fracture following both short-term and long-term use is less than that seen after conservative treatment.

In conclusion, the method described in this article provides good immobilization of the fracture without injurious compression of bone. At the same time, it permits full movement of neighboring joints, freedom of circulation in the area and full movement of muscles and tendons, early walking, full weight-bearing, and early return to managerial, administrative, and clerical occupations.

With regard to the general management of fractures, the literature and discussions tend to take two somewhat opposite views. On one hand, it is strongly contended, perhaps most recently and emphatically by Watson-Jones, that absolute immobilization of the fracture is most important and should include the joint above and the joint below the fracture. On the other hand, there have always been those who advise massage and movement with or without splinting. Perkins is a modern advocate of this form of treatment. It is only too apparent that some fractures must be immobilized and that much real trouble results from prolonged immobilization of joints, especially the encasing of joints in plaster of Paris in the presence of traumatic exudation and swelling.

The methods described in this article allow both regimens to be carried out at the same time without their respective disadvantages, but at the cost of an open operation. In this series early ambulation was a goal, but there is no reason why non-weight-bearing exercises after the advice of Perkins should not be used entirely without external support until full bone union has occurred. The method has been used successfully in compound fractures and because no external support is needed it seems especially valuable in allowing free circulation and easy dressing and skin grafting of wounds when there has been loss or subsequent death of skin and soft tissues.

Finally, what are the indications and contra-indications for the method? Experience suggests that in the tibia the method is especially valuable in the slightly oblique, unstable fracture which cannot be kept in good position in plaster of Paris and which cannot be held by screws and must, therefore, be plated to give good alignment. It is also very satisfactory in oblique and spiral fractures because an above-the-knee plaster is never required. The method enables the patient to have free ankle movement during the period of swelling and traumatic oedema, so that at a later date a below-the-knee plaster cast may be applied without causing a stiff ankle. The method is also useful when a patient suffers from a fracture of the tibia and femur in the same limb. It is especially valuable in elderly persons who tolerate plaster or extension badly. It is not required in children and is unsuitable for seriously comminuted fractures, or when there are large, loose fragments; it is unnecessary and should not be used for stable or transverse fractures.

The roentgenograms give the appearance of the use of much metal, but the weight of metal compares favorably with other plates and appliances in current use, for example:

Total weight of metal used in treatment of fracture of the tibia: 29 grams;
Standard small McLaughlin plate: 70 grams;
3¼ Smith-Petersen nail: 19 grams;
Large Eggers Vitallium plate: 26.6 grams.

NOTE: Cases 2, 10, 29, 31, 32 and 36 of the series were presented at the meeting of the Leeds Regional Orthopaedic Club on October 11, 1953 and were reported in *The Journal of Bone and Joint Surgery*, 36-B: 339-340, May 1954.

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# An Analysis of Adult Skeletal Tuberculosis*

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In this paper is presented an analysis of data collected during a study of 230 consecutive adult patients in whom skeletal tuberculosis was proved and who were admitted to the Glen Lake Sanatorium during the prestreptomycin years, 1928 to 1946 inclusive. These data are compared with the findings in two series of patients treated with streptomycin but which were otherwise similar.

The value of streptomycin in the treatment of pulmonary tuberculosis is well established. Its value is less well defined in the treatment of skeletal tuberculosis. Its effect on the bone lesion itself, that is, on tuberculous osteomyelitis, is not clear. Evaluation of this complex disease is difficult because of several factors: (1) the great variation in the extent of the lesion and in the tissue involved, (2) the chronic, often asymptomatic course with apparent cure and late relapse, (3) the lack of definite criteria of healing, and (4) currently, the lack of a large series of cases seen by any one worker.

Nevertheless, much has been added to our knowledge in recent years. Secondary infections, previously common and greatly feared, are now usually controlled with antibiotics, and the antituberculosis drugs afford that comfortable, aptly described "umbrella," under cover of which surgery may be carried out with little fear of spreading the disease.

Problems of evaluation persist, however, and some of them are basic, relating to the process of the disease itself.

The primary object of this study was to help to place our knowledge of the natural history of the disease on a more quantitative basis and to define more sharply a base line from which to evaluate the newer forms of therapy. The series of patients who underwent sanatorium care at Glen Lake Sanatorium during the years 1928 to 1946 received an accurate and prolonged follow-up. None received the newer antituberculosis drugs.

## MATERIAL

The material for the prestreptomycin series consists of 230 consecutive case histories of adult skeletal tuberculosis taken from the unusually complete case records of Glen Lake Sanatorium. Glen Lake Sanatorium received the approval of the American College of Surgeons in April 1927, the first institution of its kind in the United States to satisfactorily meet the requirements of that organization for approval. Detailed follow-up studies were obtained for 98.3 per cent of the patients in this series (four were lost)—evidence of the careful follow-up techniques in the record department of the Sanatorium. These patients were admitted during the prestreptomycin years, 1928 through 1946. Follow-up information was obtained up to January 1, 1953. The records were studied closely, and the first admission for skeletal tuberculosis of each patient during this period (1928 to 1946) was analyzed in detail. All other admissions were treated as relapses, except that a second admission within six months of discharge was considered part of the first admission.

During the period of this study, a total of 6,682 patients was admitted for treatment of active tuberculosis. The gross incidence of skeletal tuberculosis among these sanatorium admissions was 5.2 per cent.

In the philosophy of treatment at Glen Lake Sanatorium, prolonged and carefully

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* Funds for this study were supplied in part by a grant from the National Tuberculosis Association.

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regulated rest has consistently been emphasized as a primary factor in the treatment of all types of tuberculosis. In the treatment of skeletal tuberculosis, surgery was used in support of rest in the form of arthrodesis of involved joints. Accessible abscesses were evacuated, and far advanced or well circumscribed peripheral lesions were excised. Immobilization was used when indicated for symptomatic treatment and to promote rest. The approach otherwise was one of careful supportive therapy for the patient.

This integrated, planned approach was made possible by the relatively stable tenures of the full-time and the consultant staffs. Since 1928, the first year of the series, the care of skeletal tuberculosis was mostly under the supervision of one orthopaedic consultant and one full-time staff man.

TABLE I

Distribution of 230 Patients
According to the Duration of the Active Skeletal Lesion
and to the Duration of Any Known Tuberculosis Lesion

| | Active Skeletal Lesion | | Any Known Tuberculosis Lesion | |
|---|---|---|---|---|
| | *(No.)* | *(Per cent)* | *(No.)* | *(Per cent)* |
| Duration prior to admission * | | | | |
| Less than one month | 93 | 41 | 29 | 13 |
| One to six months | 40 | 17 | 40 | 18 |
| Six to twelve months | 25 | 11 | 33 | 14 |
| One to five years | 39 | 17 | 72 | 31 |
| More than five years | 33 | 14 | 56 | 24 |
| Totals | 230 | 100 | 230 | 100 |

* Determined from the time the condition was unequivocally known to be present as abstracted from the records.

Other evidence of consistency in approach is seen in an analysis of the surgical procedures done during these years. The major procedures—fusion, incision and drainage, amputations, and local excision—were done with approximately equal frequency each year, with the exception of local excision which was done more often in recent years. An analysis of this series has revealed a similar consistency as to sex, age, location of the lesion, extent of the lesion, associated conditions, and outcome.

Of considerable importance, of course, was the patients' acceptance of this regimen. Detailed study of the records revealed good acceptance, considering the long regimen which was prescribed. The patients who were ultimately discharged alive were at strict bed rest (twenty-four hours a day) for an average of one-half of the hospitalization period. (The average bed-rest period was thirteen months.) The patients had had the disease for various lengths of time prior to the admission during which they were observed (Table I).

Bacteriological proof of the lesion was demanded in all patients included in the series other than those with spinal tuberculosis. Of the patients with spinal tuberculosis, there was bacteriological proof in 26 per cent (thirty-five), proof from biopsy specimens in 10 per cent (thirteen), bacteriological proof gained elsewhere in 40 per cent (fifty-three), and roentgenographic evidence alone in 24 per cent (thirty-two).

Exclusions were as follows. Thirty-eight patients under seventeen years of age were not included in the series because the disease has certain distinct characteristics in young patients. Lack of satisfactory diagnostic proof excluded forty. Skeletal lesions which were found to be inactive after a period of observation excluded forty more. Table II is a summary of the exclusions.

There remained, then, a moderately large group of adult patients (230) with adequately proved skeletal tuberculosis who had sanatorium care without antituberculosis drugs. This series of patients provided the material for this study of the disease and was of value as one of the comparative groups for evaluation of the antituberculosis drugs. (It should be noted that, in evaluating therapy, the use of comparative groups separated in time—one group having had antituberculosis drugs, the other none—has, at best, restricted value. Ideally, control groups should be employed; for example, every patient admitted to an institution should be placed, in rotation, on the different regimens being compared.)

TABLE II

PATIENTS EXCLUDED FROM THE STUDY SERIES

| | | |
|---|---|---|
| Total consecutive admissions from 1928 through 1946 | | 348 |
| Exclusions: | | |
| Patients under seventeen years of age | 38 | |
| Lack of proof of diagnosis | 40 | |
| Inactive disease | 40 | |
| Total exclusions | | 118 |
| Patients remaining in series | | 230 |

TABLE III

A COMPARISON OF THE DISTRIBUTION OF PATIENTS BY SEX

| | | Age Group | | | | | |
|---|---|---|---|---|---|---|---|
| | Total Patients | 17 to 34 years (No.) | 17 to 34 years (Per cent) | 35 to 40 years (No.) | 35 to 40 years (Per cent) | Over 55 years (No.) | Over 55 years (Per cent) |
| Series | 230 | 113 | 49 | 78 | 34 | 39 | 17 |
| Sex: | | | | | | | |
| Male | 143 | 60 | 42* | 53 | 37* | 30 | 21* |
| Female | 87 | 53 | 61* | 25 | 29* | 9 | 10* |

* Differences are statistically significant at a confidence level of 95 per cent.

TABLE IV

AGE DISTRIBUTION OF PATIENTS

| Age in Years | Patients (No.) | Patients (Cumulative per cent) |
|---|---|---|
| 17 to 19 | 9 | 4 |
| 20 to 24 | 34 | 19 |
| 25 to 29 | 48 | 40 |
| 30 to 34 | 22 | 50 |
| 35 to 39 | 27 | 62 |
| 40 to 44 | 23 | 72 |
| 45 to 49 | 14 | 78 |
| 50 to 54 | 14 | 84 |
| 55 to 59 | 17 | 91 |
| 60 to 64 | 7 | 94 |
| 65 to 69 | 5 | 96 |
| 70 and over | 10 | 100 |
| Total | 230 | |

## METHOD

After exploratory study, six factors seemed to define the disease adequately for the purposes of this study. These six factors formed a simple basis for the organization of the study and for the presentation of the data. These data are incorporated in Tables III, IV, V, VI, VII, and XII. The factors are as follows: (1) sex; (2) age on admission; (3) location of the lesions; (4) extent of the lesions; (5) associated conditions; and (6) outcome. The following explanatory information is necessary for the interpretation of the data collected under these headings. Unless there were quite clearly normal vertebrae between two diseased sites in the spine, the lesion was considered a single focus. Prior analysis had pointed to the associated conditions listed in Table VII as significant for further detailed analysis. Others were unquestionably important, but the number of patients involved was usually too small to be of value in this study. A relapse was defined as any return to treatment for tuberculosis after the patient had been discharged for more than six months. There are no standard criteria for reactivation of skeletal tuberculosis as there are in pulmonary tuberculosis; therefore, this arbitrary, simple definition of relapse was used.

A confidence level of 95 per cent has been used as the basis for statistical significance.

TABLE V

Location of the 290 Lesions

| Location | Lesions<br>*(No.)* | Lesions<br>*(Per cent)* |
|---|---|---|
| Weight-bearing: | | |
| Spine | | |
| Cervicothoracic | 1 | 0.3 |
| Thoracic | 58 | 20.0 |
| Thoracolumbar | 19 | 6.5 |
| Lumbar | 52 | 17.9 |
| Lumbosacral joint | 8 | 2.8 |
| Sacro-iliac joint | 23 | 7.9 |
| Hip | 14 | 4.8 |
| Knee | 29 | 10.0 |
| Ankle | 8 | 2.8 |
| Foot | 9 | 3.1 |
| Non-weight-bearing: | | |
| Shoulder | 8 | 2.8 |
| Elbow | 7 | 2.4 |
| Wrist | 3 | 1.0 |
| Hand | 6 | 2.2 |
| Others* | 45 | 15.5 |
| | 290 | 100.0 |

* Includes these locations: costochondral junction, 16; ribs, 5; ilium, 4; humerus, 3; tibia, 3; os pubis, 2; trochanteric bursa, 2; soft tissue of back, 2; soft tissue of jaw, arm, and thigh, 1 each; ulna, radius, clavicle, scapula, and ischium, 1 each.

## DATA AND OBSERVATIONS

### *Sex and Age*

In Tables III and IV showing sex and age distribution, the difference in incidence between males and females is definite. There was a preponderance of males in the series which was especially evident in the older age groups. The differences between the sexes in the older age groups were statistically significant. There were no prominent sex differences apparent when location or extent of the lesions was considered; there were slightly more males than females with multiple skeletal foci and with pulmonary tuberculosis. The relapse and death rates showed similar sex differences which were unfavorable for males; this difference, as shown by Rich, is well established in studies of pulmonary tuberculosis.

The age distribution shows, as would be expected in this disease, a predominance in the younger age groups (Table IV). Almost half of the patients were between seventeen and thirty-five years of age (median age, 35.0 years). This is in keeping with the well known high incidence of pulmonary tuberculosis in the third decade of life. This high percentage of patients in the younger age group is statistically significant (Table III).

### *Location of Lesion*

The commonest sites of the location of tuberculosis in the skeletal system in this series were the spine, the knee, the hip, and the foot, in that order (Table V). These are the major weight-bearing joints. Articular disease accounted for 84.4 per cent of all the sites given in this series. Skeletal tuberculosis is a disease primarily of joints, and especially of weight-bearing joints. The rare or unusual locations cited in Table V are characteristic of skeletal tuberculosis.

TABLE VI

EXTENT OF SKELETAL LESIONS

| | | No. of Lesions | Per cent |
|---|---|---|---|
| Minimal | (1+) | 91 | 31 |
| Moderate | (2+) | 133 | 46 |
| Severe or extensive | (3+) | 66 | 23 |
| | | 290 | 100 |

TABLE VII

INCIDENCE OF ASSOCIATED TUBERCULOUS CONDITIONS

| Condition | Patients | Incidence (*Per cent*) |
|---|---|---|
| Active pulmonary tuberculosis | 117 | 51 |
| Inactive pulmonary tuberculosis | 22 | 10 |
| Active genito-urinary tuberculosis | 46 | 20 |
| History of pleural effusion | 31 | 14 |
| Abscess | 163 | 71 |
| Sinus drainage | 89 | 39 |
| Amyloid disease (proved) | 6 | 3 |
| Meningeal tuberculosis | 15 | 7 |

From the collected data concerning the location of the lesions, there are three findings of interest:

1. The relationship between the accessibility of the lesions to the skin and the development of sinus drainage. These data (Table VIII) show that 59 per cent of the lesions listed as relatively accessible to the skin had associated sinus drainage; whereas, in the case of the deeper lesions, only 26 per cent had associated sinus drainage. The difference is statistically significant.

2. The relationship between sacro-iliac lesions and multiple skeletal foci. Twelve of twenty-one (57 per cent) of the patients with sacro-iliac involvement had multiple skeletal foci, compared with forty-two of the 230 patients in the series (18 per cent). The difference is statistically significant. This is similar to the distribution found in data from Sea View Hospital reported by Cleveland in 1939. In that data the differences are also

statistically significant.* Cleveland in his report and Bosworth in a report from Sea View Hospital in 1950 say that they believe that sacro-iliac involvement is relatively more dangerous. This study supports that opinion, for there was a mortality rate due to tuberculosis of 64 per cent in the patients with sacro-iliac involvement compared with the mortality rate of 46 per cent in the entire series. The difference is not statistically significant, but the mortality rate of patients with multiple skeletal foci is equally high (64 per cent of forty-two patients with multiple skeletal foci) and, in this case, the difference is significant when compared with the mortality rate for the remaining patients in the series.

3. The relationship between the location of the skeletal lesion and its extent. Minimal lesions appeared to be more frequent in non-weight-bearing locations. While there were fifty-three minimal lesions (28 per cent) among the 192 in weight-bearing locations, there were twenty-five minimal lesions (67 per cent) in the remaining thirty-eight in non-weight-bearing locations. The difference is statistically significant. The weight-bearing locations were therefore the sites of the more extensive and the more dangerous lesions.

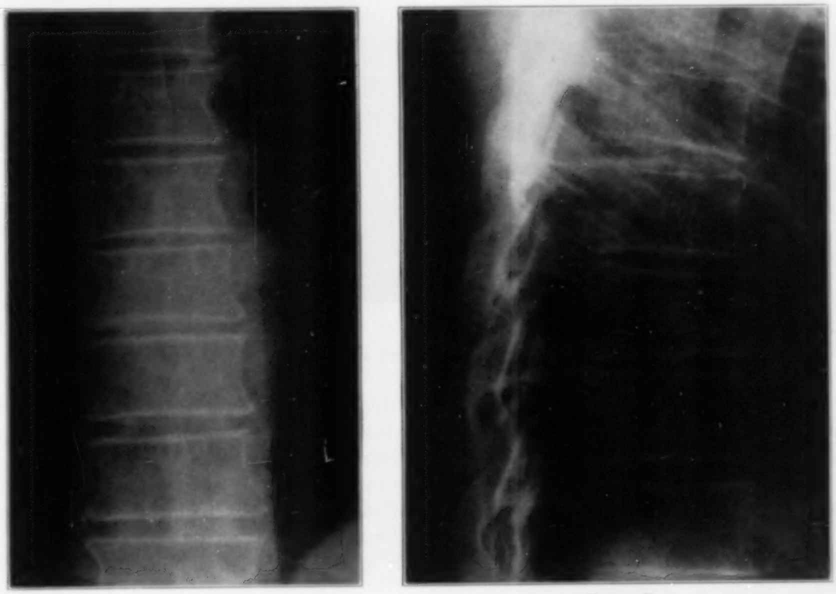

FIG. 1-A FIG. 1-B

An example of a lesion classified as minimal.

*Extent of Lesion*

In a careful, detailed analysis of a large series of patients with pulmonary tuberculosis, Foster-Carter and his associates found that the single factor which most influenced the mortality rate was the extent of the pulmonary disease. A classification by roentgenographic evidence of the extent of the osseous lesions in this series was done. Each lesion was rated according to the maximum amount of destruction of bone as follows: 1+ (minimal), 3+ (severe, extensive), and 2+ (all others). Almost half of the lesions were 2+ or moderate in extent. Severe or far advanced lesions were not uncommon in this series (Figs. 1-A through 3-B).

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* In a series of 310 patients with skeletal tuberculosis in various locations, 17 per cent (fifty-two patients) had associated metastatic spread, compared with 39 per cent (nine patients) of twenty-three with sacro-iliac disease.

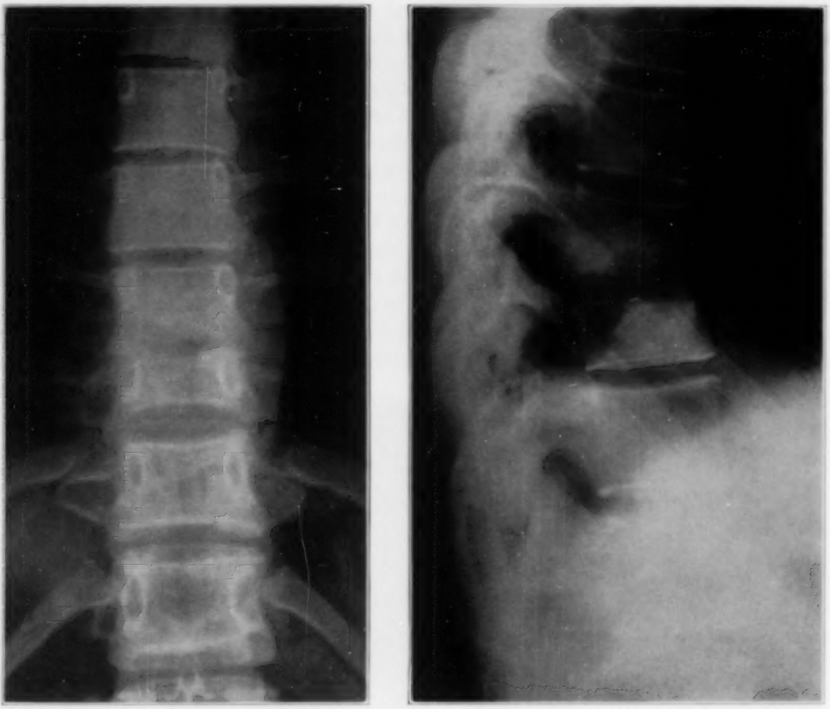

FIG. 2-A FIG. 2-B

An example of a lesion classified as moderately advanced.

In studies of pulmonary tuberculosis, the classification of the lesions by extent has a well established basis. Its usefulness is unquestioned, for judgment as to treatment and prognosis is based upon the extent of the pulmonary disease. It is logical that this principle should apply to skeletal tuberculosis. With the tuberculosis mortality rates being used as criteria, statistically significant differences were observed when the data were grouped by the extent of the skeletal lesions (Table IX). Therefore, greater accuracy may be obtained in the study of comparative series if the factor of the extent of the lesions is taken into account whenever possible.

### *Associated Conditions*

The associated conditions (manifestations of tuberculosis other than skeletal) were accurately recorded. The more frequent and significant ones are shown in Table VII. Multiple skeletal lesions were found to be quite common, there being a ratio of 1.26 active lesions per patient for this series.

Associated active pulmonary tuberculosis is commonly encountered in patients with other tuberculous lesions. The incidence in this series (51 per cent) is surprisingly high. The explanation may be that this is a series from a sanatorium to which patients were sent primarily for pulmonary disease.

Genito-urinary tuberculosis, according to Harris, is commonly found (up to 37 per cent incidence among adults) in patients with skeletal tuberculosis. The incidence in this series of patients was 20 per cent.

A history of pleural effusion was present in 13.5 per cent of the patients. In pulmonary tuberculosis as reported from this sanatorium by Hastings in 1926, the incidence was 5.5

TABLE VIII

RELATIONSHIP OF SINUS DRAINAGE AND ACCESSIBILITY OF LESIONS TO SKIN SURFACE

| | | Sinus Drainage | | | |
|---|---|---|---|---|---|
| | | Present | | Absent | |
| | Total Lesions | *(No.)* | *(Per cent)* | *(No.)* | *(Per cent)* |
| Series | 290 | 107 | 37 | 183 | 63 |
| Locations of lesions relatively accessible to skin surface: knee, ankle, foot, elbow, wrist, hand, costochondral junction, ribs, trochanteric bursa, ischial bursa, os pubis | 99 | 58 | 59* | 41 | 41* |
| Location of lesions not relatively accessible to skin surface: spine, hip, shoulder, humerus, ilium | 191 | 49 | 26* | 142 | 74* |

* Differences are statistically significant at a confidence level of 95 per cent.

TABLE IX

THE RELATIONSHIP OF THE EXTENT OF THE SKELETAL LESION AND OF DEATHS DUE TO TUBERCULOSIS, EXCLUDING PATIENTS WITH MULTIPLE SKELETAL FOCI AND ACTIVE PULMONARY TUBERCULOSIS

| | | Deaths Due to Tuberculosis | |
|---|---|---|---|
| | Total Patients | *(No.)* | *(Per cent)* |
| Series | 92 | 27 | 30 |
| Extent of lesion: | | | |
| 1+ | 24 | 2 | 8* |
| 2+ | 38 | 11 | 29* |
| 3+ | 30 | 14 | 47* |

* Differences are statistically significant at a confidence level of 95 per cent.

per cent of 1,017 cases. This difference is statistically significant at a confidence level of 95 per cent.

Abscesses, as demonstrated by clinical or roentgenographic examination, were found in about three-fourths of the patients in this series (Table VII). The incidence of draining sinuses is also given in Table VII. Draining sinuses were associated with almost two-fifths of the lesions in this series. Other associated conditions were recorded but their incidence was generally low. Amyloid disease was suspected on clinical grounds quite often but was proved by autopsy in only six instances. Miliary or meningeal tuberculosis as an important associated condition was found in fifteen patients, all of whom died. Paraplegia secondary to tuberculosis of the spine was noted in nine patients. At the end of the study, seven were dead, one was an invalid, and one was able to do only light work.

Associated conditions showed no statistically significant relationships with the other factors.

Table X shows a comparison of the mortality rates in discharged patients with a single skeletal focus, with multiple skeletal foci, and with pulmonary tuberculosis. The mortality rate increases progressively with the number of clinically evident foci. Although there are no statistically significant differences in the mortality rates of the associated conditions, the trend is suggestive.

The data raise the question of whether or not abscesses should be surgically eradicated. This question is raised by the relationship between persistence of abscesses and the higher relapse and mortality rates.

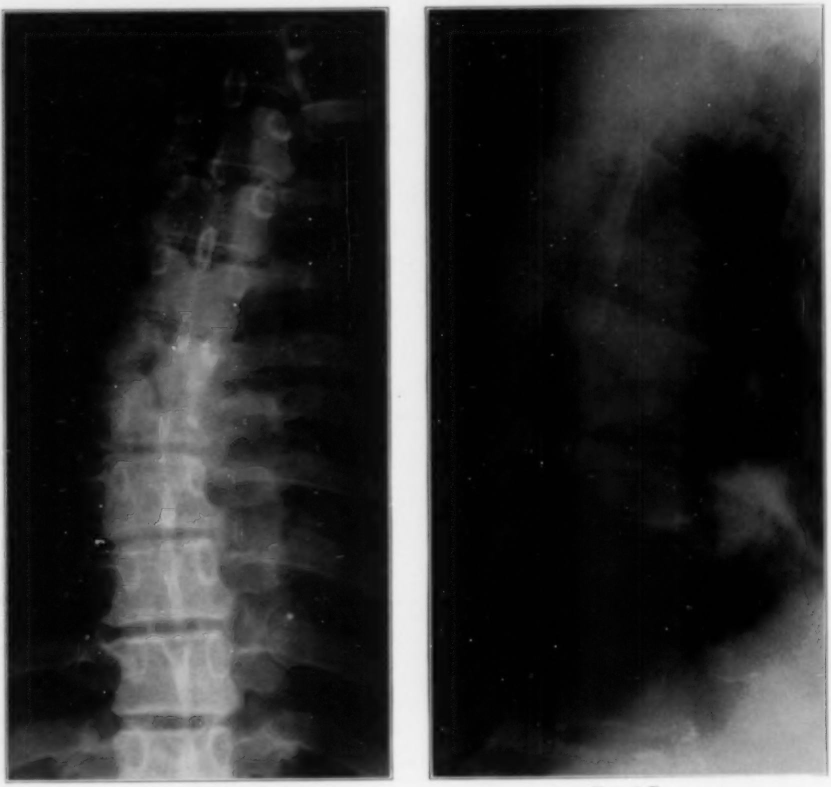

FIG. 3-A

FIG. 3-B

An example of a lesion classified as far advanced.

In the study of the case histories at Glen Lake Sanatorium, the clinical course of the abscesses was found to be well recorded. Table XI presents an analysis of this factor among the discharged patients. As criteria, relapse rates and tuberculosis death rates were used. The data indicate that since abscesses are observed to persist over progressively longer periods, there is an increase in both the relapse and mortality rates. Although the groups had progressively higher mortality rates and, hence, a progressively lessened relapse risk, they actually showed a progressive increase in relapse rates also.

The differences in these data (Table XI) are not statistically significant by the usual tests, but all of these observations, and especially the fact that the mortality and relapse rates show parallel trends, give good support to the report made by Swett and his associates.

### *Outcome*

The outcome of these cases is seen in Tables XII, XIII, and XIV. The discharges of the 148 patients who left the sanatorium alive were recorded as being *recommended*, *consent*, or *irregular* *. The distribution of discharge status for all patients admitted to the

---

* *Recommended discharge:* The patient stayed for the full treatment regimen which included carefully graduated exercises and upon discharge was able to tolerate well four hours of exercise, such as walking or light work.

*Consent discharge:* The patient had not completed the planned program of graduated exercise, but the staff by majority vote agreed that the patient was a good risk because he was being discharged to a protected environment.

*Irregular discharge:* All patients not included in the above classifications.

### TABLE X

### The Relationship of the Presence of Other Foci of Tuberculosis and Deaths Due to Tuberculosis in Patients Who Have Been Discharged

| | Total Patients | Deaths Due to Tuberculosis (*No.*) | (*Per cent*) |
|---|---|---|---|
| Series | 148 | 29 | 20 |
| Single skeletal focus only | 35 | 1 | 3 |
| Multiple skeletal foci | 28 | 4 | 14 |
| Single skeletal focus and pulmonary tuberculosis | 28 | 5 | 18 |
| Multiple skeletal foci and pulmonary tuberculosis | 17 | 5 | 29 |

### TABLE XI

### The Relationship of the Persistence of Abscess and of Outcome (Relapses and Deaths Due to Tuberculosis) in Patients Who Have Been Discharged

| | Total Patients | | Outcome | | | |
|---|---|---|---|---|---|---|
| | | | Relapses | | Deaths Due to Tuberculosis | |
| Duration of Abscess * | (*No.*) | (*Per cent*) | (*No.*) | (*Per cent*) | (*No.*) | (*Per cent*) |
| Series | 148 | 100 | 57 | 39 | 29 | 20 |
| No abscess present | 45 | 30 | 15 | 33 | 6 | 13 |
| Less than two years | 74 | 50 | 26 | 35 | 15 | 20 |
| Two to four years | 17 | 12 | 8 | 47 | 4 | 24 |
| More than four years | 12 | 8 | 8 | 67 | 4 | 33 |

* Duration of the abscess from the time of admission or from the time after admission when the abscess was first observed.

### TABLE XII

### Disposition of Patients

| Disposition | Patients | Per cent |
|---|---|---|
| Died during first admission | 82 | 35 |
| Irregular discharge | 41 | 18 |
| Consent discharge | 34 | 15 |
| Recommended discharge | 73 | 32 |
| Total patients | 230 | |

sanatorium from 1916 to 1947 is 48.3 per cent *recommended*, 20.1 per cent *consent*, and 31.6 per cent *irregular*. This distribution is not significantly different from that of the patients with skeletal tuberculosis.

Table XIII gives an account of the incidence of the relapses and the cause. Thirty-nine per cent (fifty-seven) of the patients who had been discharged had a relapse. Ten of these patients had more than one relapse. In almost half of the patients, the cause was pulmonary tuberculosis previously present. Ten per cent (six) of the patients returned to the sanatorium for treatment of pulmonary disease which had not been evident in roentgenograms made during the initial admission. This is emphatic evidence that skeletal tuberculosis is a manifestation of a systemic disease. Skeletal tuberculosis either in a new site or an exacerbation in a previously known site was the cause of relapse in one-third of the patients who returned to the sanatorium.

### TABLE XIII

Relapse among 148 Patients Who Were Discharged

| | Patients | Per cent |
|---|---|---|
| Discharged | 148 | 100 |
| Relapses | 57 | 39 |
| Cause of relapse: | | |
| Prior active skeletal tuberculosis | 11 | 19 |
| Prior active pulmonary tuberculosis | 27 | 47 |
| Another skeletal lesion | 8 | 14 |
| Another pulmonary lesion | 6 | 11 |
| Other tuberculous lesions | 5 | 9 |
| Total relapses | 57 | |

### TABLE XIV

Incidence of Death According to Cause Recorded in the Death Certificate

| Cause of Death | Patients | Incidence (*Per cent*) |
|---|---|---|
| Skeletal tuberculosis alone | 11 | 5 |
| Skeletal tuberculosis and tuberculosis in another site listed as secondary cause | 11 | 5 |
| Pulmonary tuberculosis | 31 | 13 |
| Pulmonary tuberculosis and tuberculosis in another site listed as secondary cause | 23 | 10 |
| Miliary or meningeal tuberculosis | 15 | 7 |
| Tuberculosis of adrenal glands | 3 | 1 |
| Tuberculosis of kidneys | 4 | 2 |
| Other tuberculosis | 8 | 3 |
| Total deaths related directly to tuberculosis | 106 | 46 |
| Total deaths due to other causes | 25 | 11 |
| Total deaths | 131 | 57 |
| Total patients | 230 | 100 |

The status of the ninety-nine patients who were alive at the close of the study on January 1, 1953, as to work capacity and residual deformity, is of interest. Eighty-six of these patients were capable of working full or part time. Sixteen patients considered that they had a moderate or severe residual deformity resulting from skeletal tuberculosis.

A summary of the fate of the patients is best demonstrated when the data are arranged in the modified life-table form (Table XV). Such a table is calculated according to the method of Puffer, Stewart, and Gass and is considered by statisticians to be an accurate method of presentation of this type of data. The data are arranged as if all the patients in the study were admitted for treatment at the same time. That is, 230 patients were present at the beginning, and after twenty-five years all had been dropped because there was no further follow-up. For instance, a person with a five-year follow-up, but still alive, would appear only in the first five years of the tabulated material and then would leave the series. In case of death the person would leave the series.

The survivor curve in Chart I is plotted from the data arranged in the modified life-table form of Table XV. The data relating to relapses are similarly analyzed and this curve is plotted in Chart II.

Finally, one more relationship studied seems worthy of presentation. Deaths among the irregularly discharged group were nearly three times as many as in the regularly

TABLE XV

DEATH AND RELAPSE DATA IN MODIFIED LIFE-TABLE FORM

| Year | Number Present at Beginning of Year | Number Relapsing During Year | Number Dying During Year | Number Dying of Tuberculosis During Year | Number Withdrawn Due to Study Termination During Year | Number Withdrawn Lost to Follow-up During Year | Percentage Surviving through Preceding and Current Year | Percentage Relapsing through Preceding and Current Year |
|---|---|---|---|---|---|---|---|---|
| 1 | 230 | 1 | 52 | 50 | | | 75.5 | 0.5 |
| 2 | 178 | 1 | 20 | 18 | | | 65.6 | 1.4 |
| 3 | 158 | 6 | 10 | 7 | | 1 | 61.3 | 5.1 |
| 4 | 147 | 11 | 9 | 6 | | | 57.5 | 11.8 |
| 5 | 138 | 12 | 7 | 5 | | | 54.5 | 19.7 |
| 6 | 131 | 12 | 3 | 3 | 3 | | 53.3 | 27.2 |
| 7 | 125 | 13 | 5 | 5 | 2 | 1 | 51.0 | 34.6 |
| 8 | 117 | 9 | 2 | 2 | 4 | 2 | 49.8 | 39.7 |
| 9 | 109 | 9 | 5 | 3 | 7 | | 47.4 | 45.0 |
| 10 | 97 | 7 | 2 | 1 | 5 | | 46.4 | 49.0 |
| 11 | 90 | 5 | 1 | | 8 | | 45.8 | 52.0 |
| 12 | 81 | 7 | 3 | 1 | 3 | | 44.4 | 56.3 |
| 13 | 75 | 3 | 5 | 2 | 9 | | 40.8 | 58.2 |
| 14 | 61 | 1 | 1 | 1 | 7 | | 40.2 | 59.2 |
| 15 | 53 | 1 | 2 | 1 | 3 | | 38.6 | 59.9 |
| 16 | 48 | 1 | 3 | 1 | 9 | | 36.0 | 60.9 |
| 17 | 36 | | | | 1 | | 36.0 | 60.9 |
| 18 | 35 | 1 | | | 6 | | 36.0 | 62.2 |
| 19 | 29 | | | | 3 | | 36.0 | 62.2 |
| 20 | 26 | 1 | 1 | | 3 | | 34.3 | 63.9 |
| 21 | 22 | | | | 5 | | 34.3 | 63.9 |
| 22 | 17 | | | | 7 | | 34.3 | 63.9 |
| 23 | 10 | | | | 6 | | 34.3 | 63.9 |
| 24 | 4 | | | | 3 | | 34.3 | 63.9 |
| 25 | 1 | | | | 1 | | 34.3 | 63.9 |

discharged group. The differences are not statistically significant because of the small number of patients in each group.

## ROENTGENOGRAPHIC COURSE OF SKELETAL TUBERCULOSIS AND ITS USE AS A CRITERION IN THE EVALUATION OF THERAPY

An attempt was made to determine what effect, if any, streptomycin had on tuberculous osteomyelitis by comparing this series with two others in which streptomycin was used. In order to be able to evaluate exactly the effect of the antituberculosis drugs on skeletal tuberculosis, one would like to contrive a study with certain basic features*. There would be several hundred patients who had indisputably proved skeletal tuberculosis; these patients would have been placed in comparison groups and placed on the regimens of treatment under study; the clinical and roentgenographic course of each patient's disease would be thoroughly recorded; finally, there would be an accurate, prolonged follow-up of all the patients. These data would then be collected and studied in accordance with standard statistical methods in order to determine significant differences

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* The effect referred to is the effect of the drug on the tuberculous "active destruction." This effect is shown prominently in the roentgenograms. Active destruction is precisely defined by Ferguson in his monograph on roentgen diagnosis. If streptomycin promotes the ultimate healing of a tuberculous lesion in bone, its action is to slow up or check the process of active destruction. An antituberculosis drug cannot be expected to affect other aspects of the healing process, for example, resorption of necrotic tissue and scarring or sclerosis of defects.

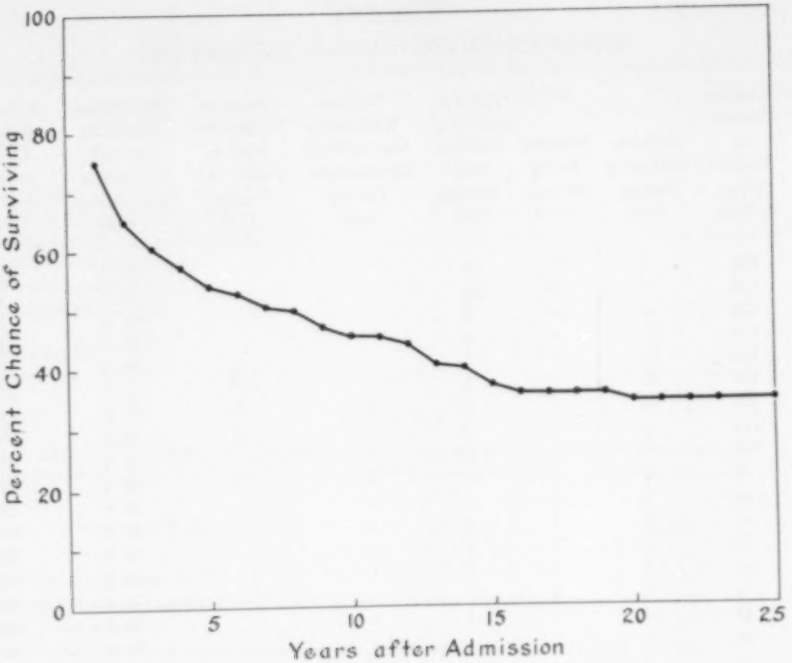

CHART I

The survival curve of 230 patients with skeletal tuberculosis admitted to Glen Lake Sanatorium (1928 to 1946).

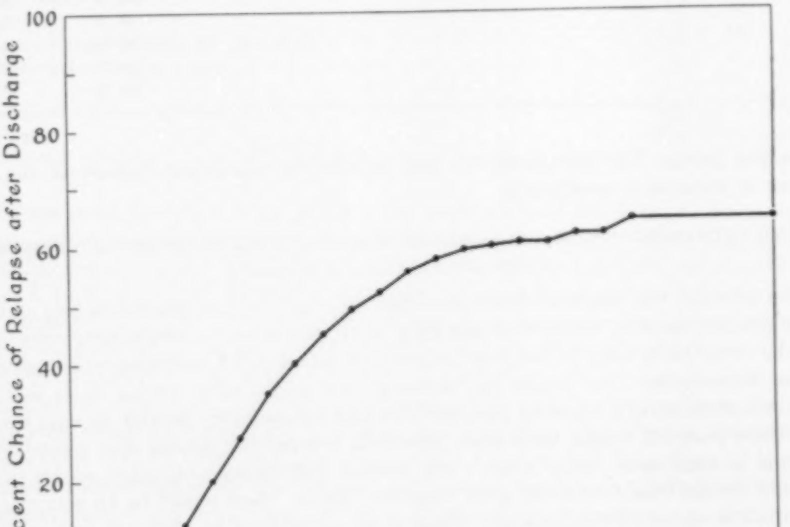

CHART II

Curve showing the chance of relapse among 230 patients admitted to Glen Lake Sanatorium (1928 to 1946).

TABLE XVI

A Comparison of the Distribution of Glen Lake Sanatorium Patients (All Patients) and Patients Rated by the Jury Prior to 1947 and After 1947

| | 1928–1946 | | | | 1947–1952 | | | |
|---|---|---|---|---|---|---|---|---|
| | All Cases | | Rated Cases | | All Cases | | Rated Cases | |
| | *(No.)* | *(Per cent)* | *(No.)* | *(Per cent)* | *(No.)* | *(Per cent)* | *(No.)* | *(Per cent)* |
| Sex: | | | | | | | | |
| Male | 143 | 62 | 70 | 57 | 26 | 67 | 12 | 57 |
| Female | 87 | 38 | 53 | 43 | 13 | 33 | 9 | 43 |
| Total patients | 230 | 100 | 123 | 100 | 39 | 100 | 21 | 100 |
| Age in years: | | | | | | | | |
| 17 to 34 | 113 | 49 | 67 | 55 | 11 | 28 | 7 | 33 |
| 35 to 54 | 78 | 34 | 41 | 33 | 13 | 33 | 7 | 33 |
| Over 55 | 39 | 17 | 15 | 12 | 15 | 39 | 7 | 34 |
| Total patients | 230 | 100 | 123 | 100 | 39 | 100 | 21 | 100 |
| Location of lesion: | | | | | | | | |
| Weight-bearing | 194 | 84 | 109 | 89 | 29 | 74 | 19 | 90 |
| All others | 36 | 16 | 14 | 11 | 10 | 26 | 2 | 10 |
| Total patients | 230 | 100 | 123 | 100 | 39 | 100 | 21 | 100 |
| Extent of lesion: | | | | | | | | |
| 1+ | 91 | 31 | 52 | 35 | 19 | 39 | 8 | 33 |
| 2+ | 133 | 46 | 73 | 48 | 23 | 47 | 14 | 58 |
| 3+ | 66 | 23 | 24 | 17 | 7 | 14 | 2 | 9 |
| Total lesions | 290 | 100 | 149 | 100 | 49 | 100 | 24 | 100 |
| Associated conditions: | | | | | | | | |
| Multiple skeletal foci | 42 | 19 | 23 | 18 | 10 | 26 | 3 | 14 |
| Active pulmonary tuberculosis | 117 | 51 | 55 | 45 | 15 | 38 | 11 | 52 |
| Abscess | 163 | 71 | 96 | 78 | 28 | 72 | 19 | 90 |
| Sinus | 89 | 39 | 51 | 42 | 16 | 41 | 9 | 43 |

among the comparison groups. At present, the ideal study would be difficult, if not impossible, to arrange. Two recent studies fulfill some of the requirements listed. One, a controlled study involving ninety patients, which was done by the United States Public Health Service, was reported in 1952. This study is relevant to the problem considered here and further reference to it will be made in the discussion. The other study, A Jury Review of Bone and Joint Cases, completed in 1949, was undertaken by the Veterans Administration cooperative group. In that study, 196 proved cases of skeletal tuberculosis, almost all of which were in male patients who had received streptomycin, were analyzed. Compared with this group were forty patients who had not received streptomycin, chosen as a pilot group from the case records of Glen Lake Sanatorium. The principal criterion used in evaluating the effects of streptomycin, as in the Veterans Administration cooperative pulmonary studies, was the roentgenographic course of the tuberculous process.

To add significance to the Veterans Administration cooperative study, a larger group of patients who had not received streptomycin was desirable for comparison. The pilot group of forty patients from Glen Lake Sanatorium was therefore expanded as a part of the study already presented in this report. This part of the report deals with that larger group of patients and with roentgenographic comparisons with streptomycin-treated patients. Complete roentgenographic files were obtainable of all patients in the pre-streptomycin era at Glen Lake Sanatorium. These roentgenograms were consistently of a quality comparable to those of the streptomycin-treated patients of the Veterans Administration study. Roentgenograms alone show little of the undoubted beneficial effects of streptomycin in bone and joint tuberculosis. However, they are highly objective.

Three groups were used in this comparative study. The first group, patients who did not receive streptomycin, consisted of the 230 patients analyzed previously. Roentgenograms of 123 of these patients (149 lesions) were available which had been made frequently over a period long enough to give a good indication of the course of the patient's disease. These were the juror-rated cases. The other patients either died soon after admission or they left the sanatorium before a significant clinical and roentgenographic course was apparent. There were no roentgenographic studies available for twenty patients, observed clinically for more than one year, because the films were lost or were inadequate, or because the lesion involved soft tissue only. The data of the second group, the 196 patients treated with streptomycin who were studied by the Veterans Administration cooperative group, are recorded in the Minutes of the Eighth Streptomycin Conference. Certain of these data were chosen for comparative purposes for this report. The third comparative group consisted of a small number of patients treated with streptomycin at the Glen Lake Sanatorium from 1947 through 1952, of whom twenty-one (twenty-four lesions) of the total thirty-nine patients (forty-nine lesions) had adequate roentgenograms available for study. These were juror-rated cases. This group of patients was given streptomycin therapy in addition to the usual treatment. Although this was a small group of patients, they were included because they were from the same institution as the first group, and were treated at about the same time as the second group.

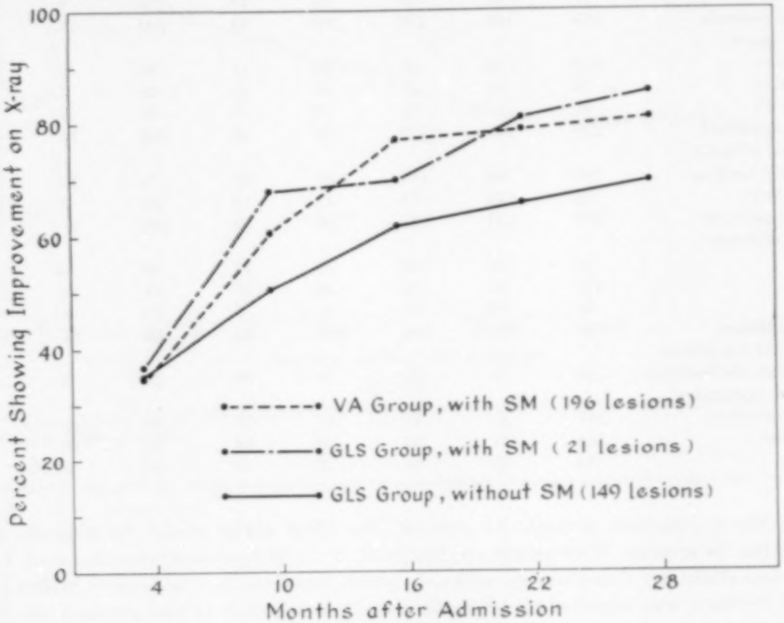

CHART III

A comparison of rate of healing by roentgenographic study of streptomycin-treated lesions and lesions not treated with streptomycin.

The patients treated with streptomycin received variable amounts of the drug. In the Veterans Administration cooperative study, the patients generally received a gram a day for four months without other antituberculosis drugs. The Glen Lake Sanatorium patients, since they were treated later, received drug therapy usually up to one year, and often received para-aminosalicylic acid as a second drug.

The background information on the two Glen Lake Sanatorium groups is given in Table XVI.

The roentgenographic course of the lesions in all three comparative groups was reviewed by the same three orthopaedists*. This was done in 1949 for the Veterans Administration cooperative group and in 1953 for the two Glen Lake Sanatorium groups in this study. The roentgenograms were reviewed independently, with the jurors in separate rooms and with no other data available. With the help of assistants, they viewed the roentgenograms quickly and marked with checks or numbers the forms provided to indicate their choices. The jurors made comparisons between the first roentgenogram available of each patient and those made at intervals of about every six months for the first two years of treatment and thereafter at yearly intervals. In making these comparisons, each juror scored his opinion of the patient's improvement or worsening.

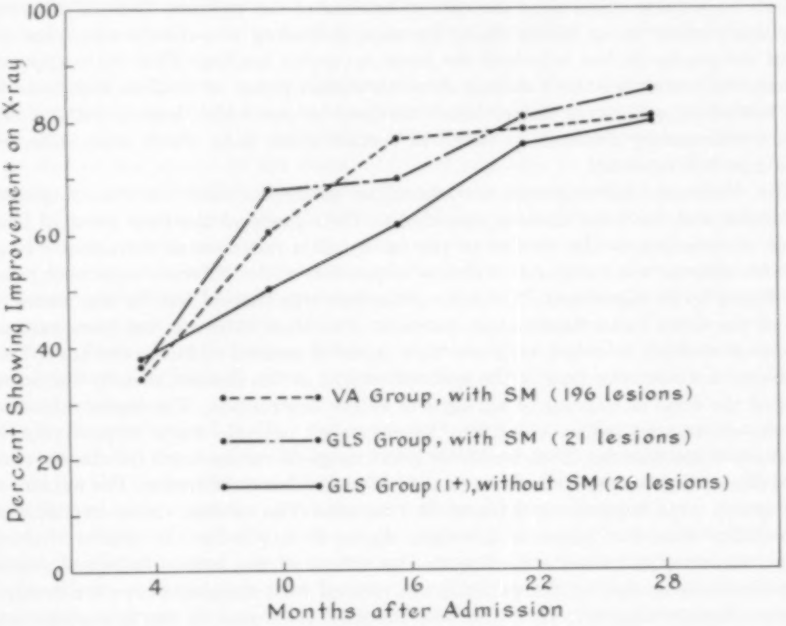

CHART IV

A comparison of rate of healing by roentgenographic study of streptomycin-treated lesions and lesions not treated by streptomycin but which showed the most favorable healing.

In Chart III the data concerning all patients treated with streptomycin are compared with data on patients who received no streptomycin. There appeared to be superior healing of the bone lesions in the patients who had been treated with streptomycin. The difference between the Veterans Administration cooperative group and the Glen Lake Sanatorium group is statistically significant (confidence level of 95 per cent) at the sixteen-month period.

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* Dr. William Bickel, Mayo Clinic, Rochester, Minnesota; Dr. Edward T. Evans, University of Minnesota, Minneapolis, Minnesota; and Dr. Ralph K. Ghormley, Mayo Clinic, Rochester, Minnesota. These three jurors had also reviewed the cases collected for the Public Health Service cooperative investigation in 1952.

Detailed data of the jury review held in 1949, as reported in the Minutes of the Eighth Streptomycin Conference, showed agreement among these jurors in scoring changes in roentgenograms which was considered quite remarkable.

The rate of healing in the Glen Lake Sanatorium group was similar for the patients who were treated from 1928 through 1933 and those treated from 1940 through 1946. One would presume, then, that the difference in the patients in the 1947 to 1952 group treated with streptomycin was not due wholly to the period in which treatment was given, that is, to generally improved medical care.

To add more meaning to the differences shown in Chart III, a second comparison, Chart IV, is presented, showing the differences in healing between the groups of patients not receiving streptomycin, but showing the most favorable healing, and the patients receiving streptomycin. In all the patients in the groupings explored (sex, age, location of lesions, extent of lesions, and associated conditions) who were not treated with streptomycin, lesions of minimal extent (fourteen) showed the most favorable healing. Therefore, Chart IV appears to show that the rate of healing of the patients treated with streptomycin was similar to, or better than, the rate of healing of patients who were treated without streptomycin but who had the most favorable healing. That is, it appears that streptomycin converted the Veterans Administration group of random lesions to lesions which healed as well as, or better than, minimal lesions which healed without streptomycin. Confirmatory evidence is found in certain other data which were collected and analyzed as will be noted.

The Veterans Administration cooperative group, in their studies of pulmonary tuberculosis with cavitary disease, specified in their protocol the time interval from the start of observation to the closure of the cavity as a criterion of therapeutic response. When this interval was compared in groups of patients under different treatment regimens, it was found to be significant. A similar procedure was carried out by the jurors in this study of the Glen Lake Sanatorium patients. The time intervals between various end points were studied; however, only one time interval seemed to have relevance. This was the interval between the time of the greatest extent of the disease, usually the admission date, and the time of clearing of all signs of active destruction. The mean values for the streptomycin-treated patients and for the untreated patients were, respectively, eleven and twenty-three months. Because of the great range of values, tests for chance variation showed the average values to have no statistically significant difference. The median values for the group were respectively 9.0 and 10.3 months. The median values probably reflect more validity than the means or averages. Again to emphasize the degree of these differences, the median values according to the extent of the lesions (minimal, moderate, and extensive or severe) in the patients not treated with streptomycin were investigated and were, respectively, 8.7, 12.4, and 15.7 months. Here also, in the groupings explored (sex, age, location of lesions, extent of lesions, and associated conditions), in all patients not treated with streptomycin, those with minimal lesions showed the most favorable healing or, in this instance, the shortest time of healing (8.7 months). The results of streptomycin treatment again were that in all of the patients treated with streptomycin the lesions appeared to have been converted to minimal lesions.

The number of patients in this study is large but the results do not offer absolute proof of the helpful effect of streptomycin. Although there is one statistically significant difference, it is best to be cautious in drawing conclusions because of the different periods of time of treatment of the two major comparative groups.

## DISCUSSION

The criteria used in evaluating skeletal tuberculosis in this study were the changes seen in the serial roentgenograms. The principal finding, which is most consistently present for analysis in the roentgenograms, is the characteristic finding of tuberculous osteomyelitis, that is, the active destruction of bone tissue.

The effect of streptomycin on tuberculous osteomyelitis from a roentgenographic standpoint is not clear. This is attested by the fact that no worker has ever reported any striking effects, by the fact that spread of bone infection or new bone lesions have been observed while the patient was receiving streptomycin, and by the fact that the Public Health Service study of 1952, using control groups, showed an effect but one that was not apparent roentgenographically, that is, there were statistically significant differences when other clinical criteria were used, for example, sedimentation rate.

The effects of streptomycin on soft-tissue tuberculous lesions are considerable, and sometimes even dramatic. Because of this, one would expect some healing effect upon the tuberculous osteomyelitis. Animal experiments by Bastos Mora and Portal Llamedo in 1955, in which tubercle bacilli were implanted in bone, showed a definite effect on the osteomyelitis by streptomycin, one in which "the main action of the drug is to inhibit the spontaneous progressive course of the process." The data presented in this paper also appear to show a definite effect of streptomycin on the osteomyelitis, but it is an effect that is discernible only in a large group of patients after prolonged follow-up with frequent roentgenograms.

In pathological terms, it is difficult to conceive of a dramatic cure of an advanced tuberculous infection of the bone in the way that penicillin cures an acute infection of syphilis or pneumococcal lobar pneumonia. The difficulty in a tuberculous bone infection may be due to the nature of the tissue involved and also to the nature of the disease. Tuberculosis is a necrotizing disease and frequently causes defects in tissue which, in the case of bone tissue, are difficult to heal and to repair. That there are difficulties in healing bone infections, generally, is shown when staphylococcal osteomyelitis is compared with staphylococcal infections in soft tissue. Penicillin, for instance, is usually very effective against staphylococcal soft-tissue infections, but in chronic staphylococcal osteomyelitis it appears to be less effective. The physiological microtraumata of use in bone perhaps play a part. They are ordinarily a factor in strengthening bone by producing resorption and remodeling along lines of stress, but their effect in infected bone tissue is probably to promote the infection.

While the problem of skeletal tuberculosis is one of diminishing importance, it still poses problems for the medical profession; nevertheless, progress is being made and the prognosis for the patient is now considerably improved. The time, however, for talking confidently and unequivocally about the cure of the disease is not yet here. Streptomycin is now more efficiently used than it was in the period prior to 1952, the time of the studies detailed here. Toxicity and resistance are no longer the problems they once were. Therefore, the effect on skeletal lesions by streptomycin and by other recently discovered antituberculosis drugs may now be more definite. While the roentgenographic status of the bone lesion may not reflect great alteration by the use of these drugs, the ultimate effect on the relapse and mortality rates among patients with skeletal tuberculosis will undoubtedly be great. Time alone, and studies with careful follow-up, will reveal this.

Further experience with antituberculosis drugs may show that evacuation or excision is not necessary. That is, the tissues may be saturated sufficiently under the long-term therapy in current use to eradicate the tubercle bacillus. In that case, drug therapy alone would achieve cures. This could apply especially to early, minimal, well circumscribed lesions in vascular areas and would be comparable to the successful treatment with penicillin of early hematogenous osteomyelitis.

## SUMMARY AND CONCLUSIONS

Data were presented from a series of 230 consecutive adult patients with well proved, active, skeletal tuberculosis. It was found that a majority of the patients were young men and that the disease was located in weight-bearing joints, especially in the axial skeleton. The lesions were usually of advanced extent and were often associated with other tuberculous conditions, especially pulmonary tuberculosis, other skeletal tuberculosis foci, genito-urinary tuberculosis, previous pleural effusion, abscesses and drainage.

During the six to twenty-five-year follow-up period there was a mortality rate due to tuberculosis of 57 per cent for all patients and a relapse rate of 39 per cent for all patients discharged.

It was shown that factors which had proved to be statistically significant in relation to an increased mortality rate were the location of the lesion, the extent of the lesion, the presence of multiple skeletal foci, and the presence of pulmonary tuberculosis.

With the material on the 230 patients used as a comparative group depicting the disease prior to the use of streptomycin, comparisons were made with two other groups of patients who received streptomycin. It is inferred that the effect of streptomycin on the osseous component of tuberculosis is slight but definite.

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# Instruments for Use with Flexible Steel Wire in Bone Surgery*

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Many surgeons have felt that stainless-steel wire could be of greater advantage than it commonly is in bone surgery. Wire loops hold bone fragments in contact; they cannot hold them apart as plates and screws may do. They introduce a minimum of foreign material into the wound, and they require a minimum of surgical exposure for placement. However, in the past when strong fixation was demanded, wire loops were frequently untrustworthy; they were liable to break sooner or later. There are several reasons for this. Sometimes wire of insufficient caliber was used, and the wires were placed inadequately. However, a major cause of failure of wire loops was excessive strain on the basic twist, applied at the time of tightening. This occurred because tightening and twisting were performed in the same maneuver.

An instrument was developed fifteen years ago which allowed the separation of the maneuvers of tightening and twisting, and which embodied the principle of a coil spring to vary and to measure tension. The first model contained both a light spring for use with small-caliber wires, and a heavy spring for larger wires. This instrument functioned well on extensive use over a period of five years.

Experience demonstrated, however, that having two sizes of spring in the wire tightener was an unnecessary complexity. It became apparent that the small surgical wire employed on bones of the hands and feet did not warrant a special instrument. Only wires that had to resist the greater stresses of major bones required a precise method of tightening and twisting. Therefore a modified tightener, incorporating a single heavy spring, was constructed (Fig. 1, *A*). During ten years of use by competent surgeons, this model has proved its value in protecting wire loops from breaking due to uncontrolled strain.

Since it was established that flexible steel wire could be thoroughly relied upon if properly applied and tightened, it seemed practical to develop two further devices to expand its usefulness. They also have been well tested in surgery. The wire-washer set (Fig. 1, *B*) is composed of a flattened wire loop and a pair of steel washers to hold bone fragments together. The C clamp, with removable drill guide and special drill (Fig. 1, *C*, *D*, and *E*), facilitates fixation of certain difficult fractures.

## WIRE TIGHTENER AND TWISTER

This instrument has two special features not embodied in the usual devices used for tightening and twisting loops of wire in bone surgery.

1. It permits a desired degree of tension to be reproduced accurately. In order to effect this, the ends of the loop are drawn up against a calibrated spring. Tension is judged by counting notches on a scale (indicated by the arrow in Fig. 1, *A*). Thus the optimum tension for a given caliber of wire, as determined by experience, can always be obtained.

2. It permits the ends of a wire loop to be twisted without putting excess strain on the first turn, where a loop is liable to be broken or seriously weakened. This is accomplished by pulling the wires up crossed at the tip of the instrument (Fig. 2). Then, after the desired tension has been registered, a half turn of the tip will lock the wires where

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* Based on a Gadget and New Ideas Exhibit presented at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 26 to 31, 1957.

they cross. Twisting is thus an entirely separate maneuver from tightening. Progressive twisting automatically holds wire tension constant, thereby protecting the first twist from mounting strain. Once the wire ends have been correctly inserted and clamped in the instrument, tightening and twisting are accomplished rapidly by simple maneuvers which no longer require the wire itself to be visualized in the wound.

Various sizes of wire may be employed with this tightener, but the coil spring has been calibrated particularly for use with the heavier sizes which have been found most suitable on extensive use in the surgery of major bones, that is, 18-gauge and 20-gauge surgical stainless steel.

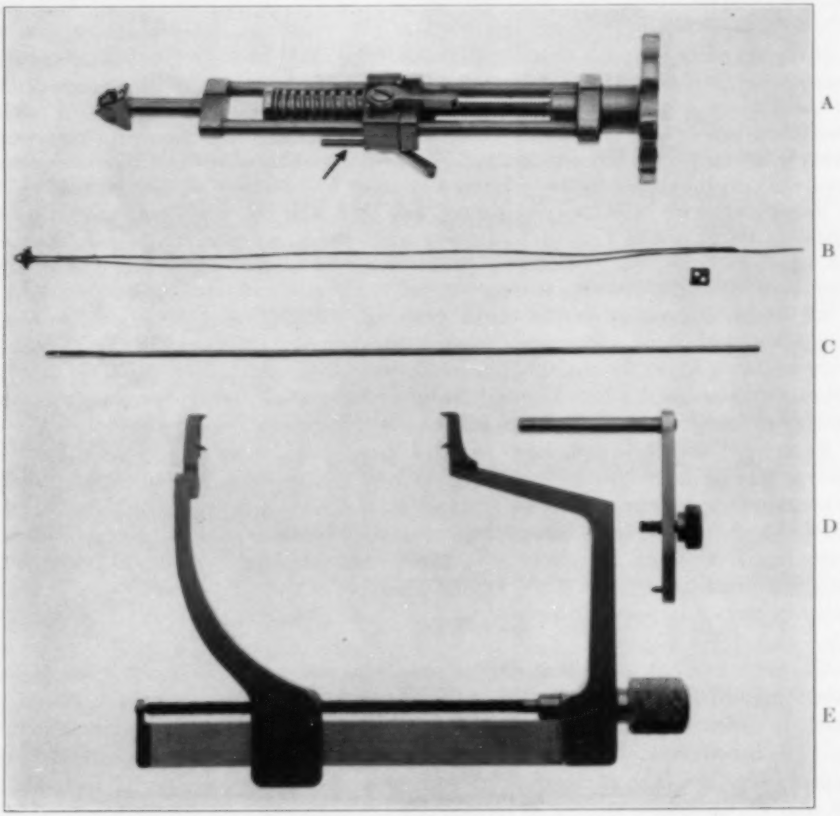

FIG. 1

Fig. 1, *A*: Wire tightener (arrow points to notched rod which constitutes tension scale); *B*, wire-washer set; *C*, drill with eye through tip; *D*, detachable drill guide; and *E*, C clamp.

*Manner of Use*

A sufficient length of wire is cut from the spool and is passed around the bone fragments to be secured. The free ends of the wire must be crossed, and are only then threaded through the tunnels on either side of the tip of the instrument. The letters *T* for *top* and *B* for *bottom*, stamped on the tip, indicate how the wires should lie as they cross each other (Fig. 2). (This is essential for correct twisting subsequently.) The wires are then led straight back to the two self-locking clamps. Before clamping, a pair of pliers is used to take up the slack of each wire separately, thereby maneuvering the tip of the tightener to the position where one wishes the twist ultimately to be (Fig. 3). If the loop makes a sharp bend (for instance, on emergence from a drill hole), tightening and twisting are best done at that point. (This is exemplified in the illustrations, as the wire loop is being tightened at one corner of the wooden block.)

The wire loop is first tightened by turning the knob to the right (clockwise), with care taken to hold the instrument firmly so that the wires remain correctly crossed at the tip. Tightening is continued until the coil spring is fully compressed, in order to seat the wire snugly against bone (Fig. 4). However, the loop must not remain that tight.

Next, compression of the coil spring is partially reduced by turning the knob to the left until the desired final tension at which to twist the wires is registered on the scale. One reads the tension scale by counting the notches that protrude beyond the movable block of the instrument. A position with five notches protruding is commonly used as the final tension for 18-gauge wire (Fig. 5). With 20-gauge wire, the final tension should be less by two or three notches.

Finally, the wire ends are twisted (Fig. 5) by rotating the main body of the instrument to the right (if the wires be properly crossed at the tip), while at the same time the knob is held in a stationary position. This is equivalent to progressive unscrewing of the knob, which automatically reduces tension of the coil spring as twists are taken, thereby eliminating stress from the first turn of the wires. A slight longitudinal pull should be maintained on the instrument, transmitted by the hand holding the knob, so that the twists will form symmetrically at the tip (Fig. 6).

After twisting is completed, the wires are cut loose at each side of the tightener with care taken to keep one's fingers clear of the snapback of the coil spring. The twisted end is then cut off to the desired length. It should be bent down at right angles to the plane of the wire loop, so as not to disturb its tension.

## WIRE-WASHER SET

The wire-washer set is a device to draw certain types of bone fragments together and then to secure them (Fig. 7). It acts like a bolt with washers and nuts, but is much more versatile in application. The method of fixation, that is, use of the wire tightener, assures that a precise and reproducible amount of compressive force is always employed.

Each wire-washer set consists of a pair of square two-holed washers, or buttons, and a flattened loop of wire to connect them. The sets are made up with one washer in place at the closed end of the flattened loop, and the other washer loose (Fig. 8). The free ends of the loop are brazed together, so that the tip of only one wire extends beyond the point of fusion. This tip facilitates passage of the two wires through a single drill hole. After the bone is traversed, the wire ends are separated, the second washer is passed over them, and the wire tightener is then applied.

The square washers are made with their corners bent over slightly to form points which will bite into bone cortex. The wires and washers are stainless steel. Three sizes of washer and two gauges of surgical wire, 18 and 20, are commercially available in combinations to meet various conditions. Thinner bone cortex requires a larger washer in order that the pressure may be distributed.

### *Manner of Use*

A hole is drilled through the bone fragments in the most advantageous position for fixation. The tip of a wire-washer set is passed through the drill hole until the washer at its closed end lies against bone cortex. The brazed portion is then cut off and discarded, so that two ends of wire are left free to be threaded through the second washer. Cutting one of the wire ends slightly shorter than the other makes it easier to pass the wires through the two holes of the washer. This washer, with its bent-over corners facing bone, is slid down the wires into contact with cortex.

The wire tightener is then applied, with its tip pressing against the washer (Fig. 9).

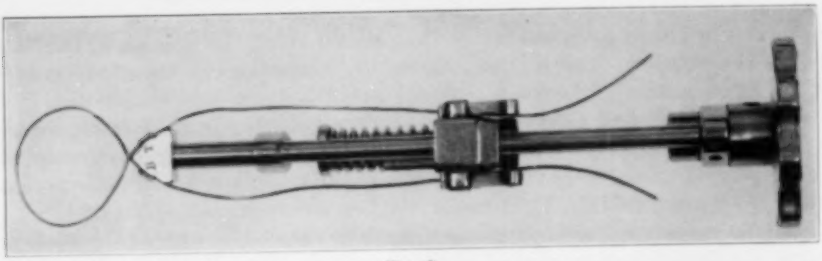

FIG. 2

Manner in which wires are crossed at tip of wire tightener is illustrated.

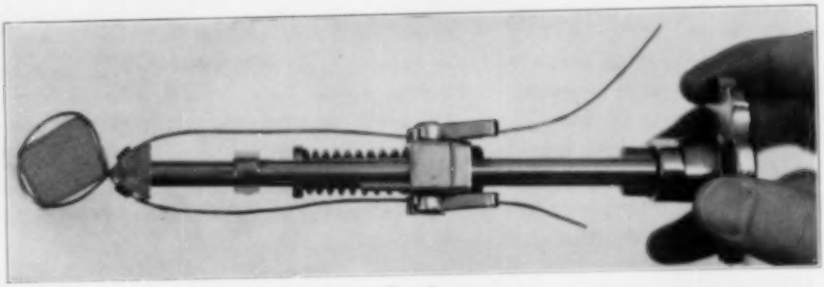

FIG. 3

Wires have been passed around object and clamped in tightener; before any tightening is carried out, the tension scale protrudes fully and all notches are visible.

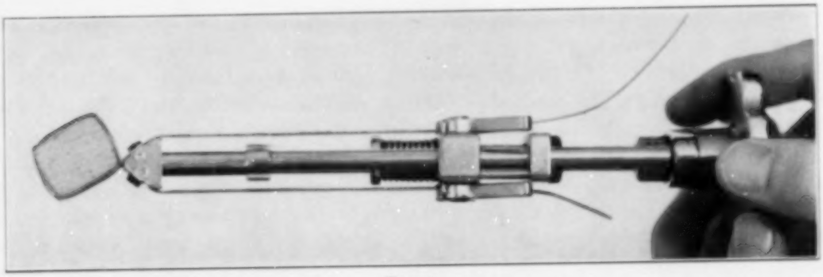

FIG. 4

Photograph showing position after initial tightening; the coil spring is fully compressed and the movable block covers the last notch of tension scale.

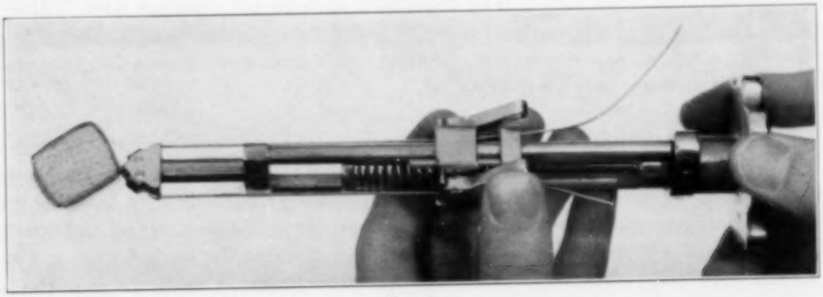

FIG. 5

The tension has been partially reduced; five notches show on the scale (for 18-gauge wire). Twisting of the wires is about to be started.

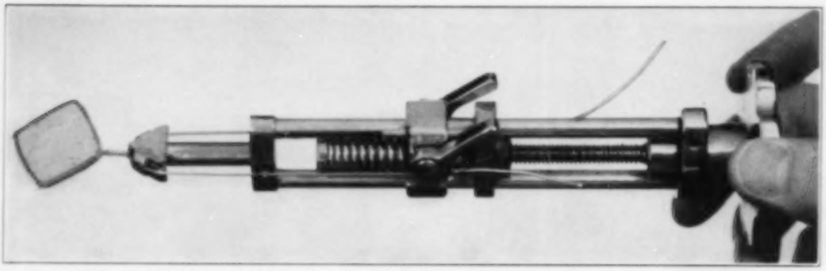

FIG. 6
The twisting has been completed under constant tension.

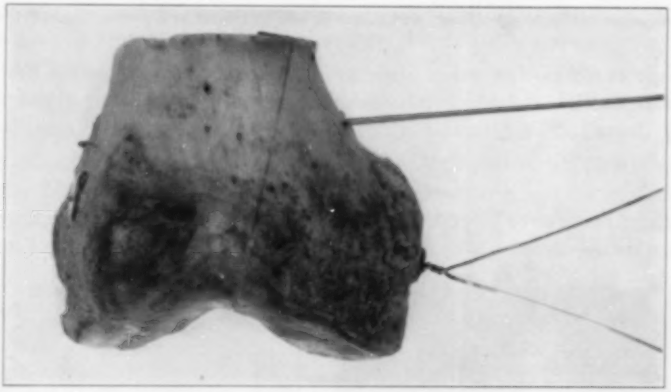

FIG. 7
A wire-washer set and a Kirschner wire are in place.

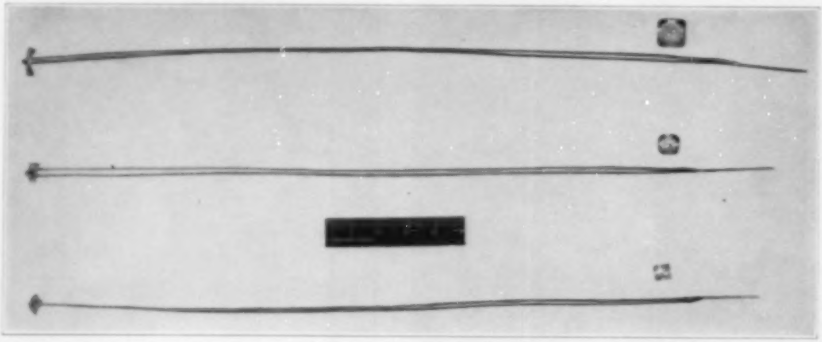

FIG. 8
The wire-washer sets as made up are shown.

In this instance, the wires are passed through the tunnels at the tip without being crossed first. The washer itself holds the wires close enough together to permit subsequent twisting without putting excess strain on the first twist. As long as spring tension is not too great, the coil spring of the tightener will absorb whatever stress is produced by the basic twist against the washer.

Except that the wires are not crossed before tightening, the technique of using the wire tightener is the same as has been described for tightening and twisting wire loops. However, certain details must be observed with respect to the presence of the washer. It is essential that the tip of the tightener be centered on the washer in order to permit the

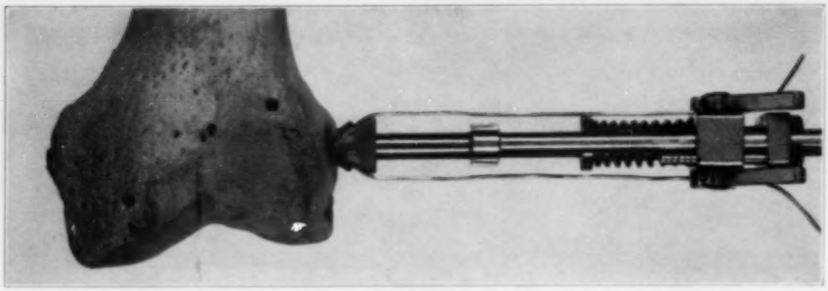

FIG. 9

A wire-washer set is being tightened; the tip of the tightener is centered against the washer.

washer to slide easily on the wires. Since twisting is carried out against the washer, the washer must be fixed. It must be firmly seated against bone so that it will not rotate during the twisting. Initial full tightening of the wires, carried out to total compression of the coil spring, will seat the washer thoroughly. But tension must then be partially released—as whenever the tightener is used. If subsequently the washer should tend to rotate during twisting, it must be gripped by a Kocher clamp or equivalent instrument.

This procedure provides strong longitudinal fixation. The addition of auxiliary wire

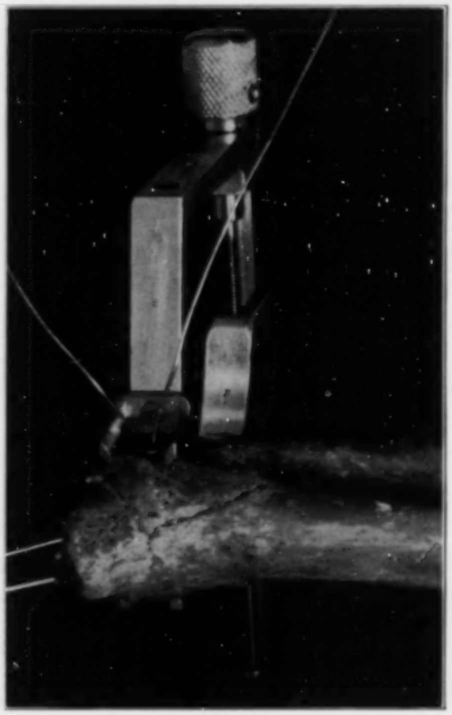

FIG. 10

The C clamp is in place and a wire-washer set is being applied.

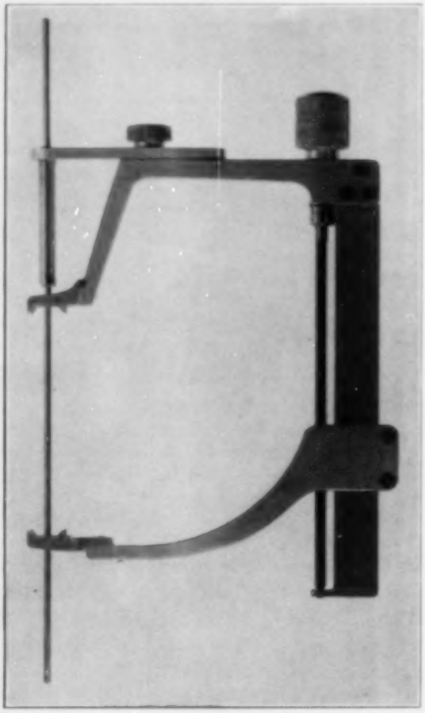

FIG. 11

The C clamp with the drill passed through attached guide is shown.

loops, or the drilling of a Kirschner wire through bone fragments (Fig. 7), may be indicated to enhance lateral stability. In any event, a minimum of foreign material is introduced.

### C CLAMP WITH DRILL GUIDE

The C clamp is designed to maintain fracture fragments about various major joints in accurate position while internal fixation is carried out with a wire-washer set and the wire tightener. By appropriate location of the clamp, the attached drill guide permits exact placement of the drill hole through which the wires are to be passed. (Figure 10 shows the clamp in position.) The special drill, commercially available, has an eye through its tip (Fig. 1, *C*) to aid in drawing wires through bone.

This apparatus is particularly valuable in the treatment of posterior-lip fractures of the lower end of the tibia (Fig. 10), where fixation of the articular surface in exact alignment often proves difficult. In such cases, when the proximal jaw of the clamp is introduced through the main posterolateral surgical incision, the other jaw readily reaches around the ankle to a counterincision anteromedially.

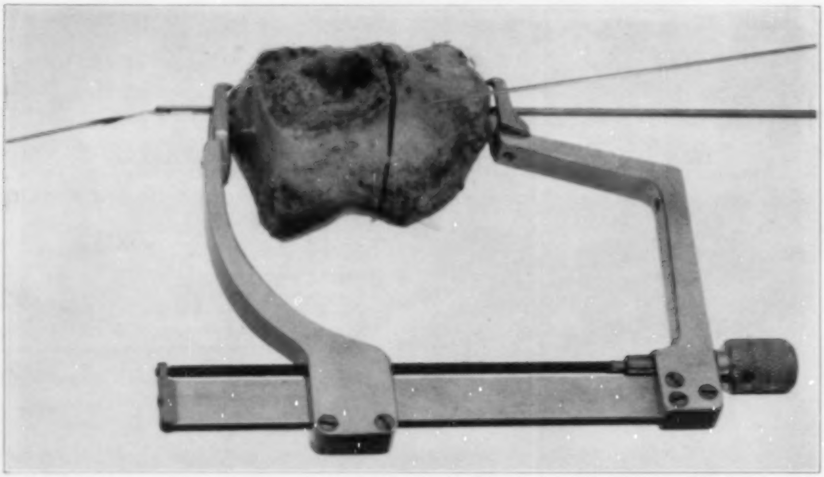

FIG. 12

The tip of the wire-washer set secured to the drill is shown.

The jaws of the clamp draw down in parallel planes so that they always bear the same relationship to each other except for distance. The clamp is constructed largely of aluminum for lightness in handling, but each jaw is armed with a steel tip consisting of two parallel prongs with small teeth (Fig. 10). Between the prongs of each tip the drill is directed by the drill guide (Fig. 11). The prongs at the tip of the proximal jaw are shaped to allow the wire tightener to be applied there while the clamp is in position on the bone. The drill guide is removable (Fig. 1, *D*) to give clearance for manipulating the wires.

### *Manner of Use*

After reduction of the fracture, the fragments are secured with the aid of the C clamp. It is important that the clamp be placed accurately in the position which will be best for fixation by a wire-washer set.

With the use of the special drill and guide, a hole is drilled through the bone fragments. The drill will pass between the prongs of each jaw of the clamp. The drill guide should then be detached. The tip of a suitable wire-washer set is next threaded through the eye of the drill as it emerges from bone, and the wire end is clinched with pliers

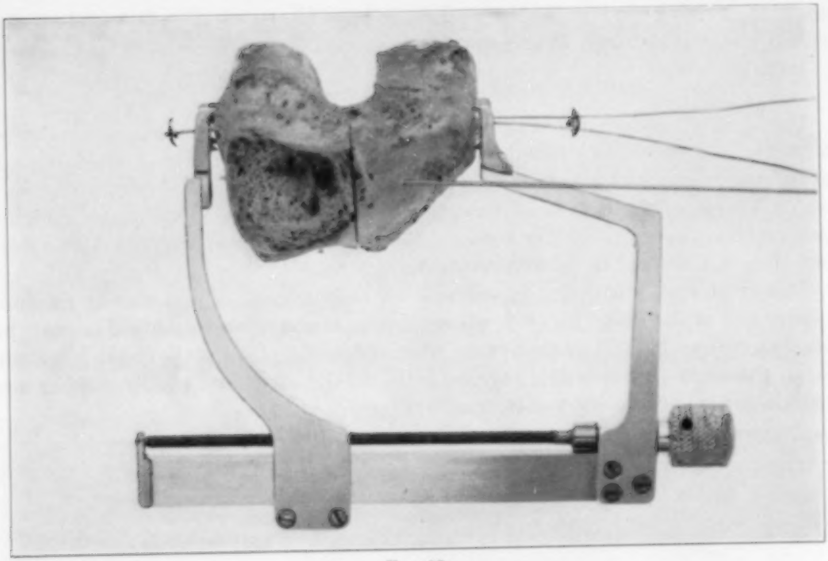

FIG. 13

The doubled wire is through the drill hole. The washers are on the wires.

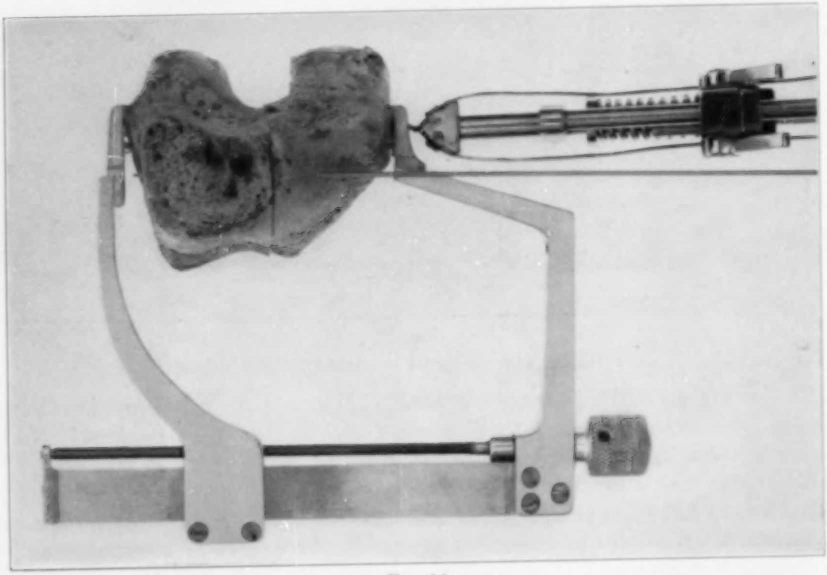

FIG. 14

The wire tightener is being applied with the C clamp in place.

(Fig. 12). The drill is withdrawn from the bone, pulling the wires behind it, until the washer at their end comes to rest against cortex between the distal prongs of the clamp. The fused tip of the wires is cut off, and the second washer is slid into position between the prongs of the proximal jaw of the clamp (Fig. 13). Finally, the wire tightener is applied in the manner described as routine procedure for securing a wire-washer set (Fig. 14). During twisting, the second washer must be well engaged against bone cortex (or must be gripped firmly) to prevent its rotation. Before removal of the clamp, it is frequently advisable to drill an auxiliary Kirschner wire, or wires, through the bone fragments. With ankle fractures especially, it is sometimes helpful to impale comminuted fragments with Kirschner wires even before the clamp is first applied (Fig. 10).

## COMMENTS

The devices described are offered as aids to the surgeon who employs stainless-steel flexible wire in bone surgery. The subject of wire fixation, with representative cases illustrating results obtainable by use of these devices, will be presented in a subsequent paper.

I have used the wire tightener routinely over a period of fifteen years on busy orthopaedic services in military and civilian hospitals. A number of the tighteners have also been employed by other surgeons. Wire-washer sets have been in use for over eight years, and the C clamp for three or four years. In my own experience, over-all results have been excellent. The failures have been attributable to factors other than the surgical appliances.

The wire tightener will always function well if it is used according to the precise instructions illustrated. The tension which one desires is assured by reference to the scale incorporated in the instrument. If twisting is carried out correctly, the tension will remain approximately the same while the turns are being taken. As many twists as one wishes may be added without putting additional strain on the wires that pass through or around the bone. Weakening and breaking of wires can be avoided. Use of circumferential wires about the shaft of a long bone does not appear to weaken the bone. No secondary fractures attributable to the use of wire loops have come to my attention. A strand of wire does not produce the relatively broad zone of potential cortical necrosis that a Parham band does. Callus surrounds the strand of wire readily.

Wire-washer sets provide excellent fixation for fractures about large joints and for oblique shaft fractures. In the latter instance they should always be supplemented by wire loops for control of rotation of the fragments. Very few wire-washer sets have failed to maintain their fixation. Of course, fixation must be strong enough to resist the forces which will be applied to the bone. Inadequate wiring will fail, just as will inadequate plating. That strong fixation by wire alone can be obtained was demonstrated in the case of an elderly woman with a spiral fracture of the lower portion of the shaft of the femur. After internal fixation with two wire-washer sets and four wire loops had been performed, she heedlessly got out of bed and walked on the day after the operation and on several subsequent days. There was no change in the position of the fragments.

Proper tension for applying wire-washer sets, as for wire loops, is a matter of surgical judgment and experience. Fixation of fractures through cancellous bone requires less tension than fixation of shaft fractures. Excess tightening may bury a washer in a femoral condyle. The larger washers should be used against thin cortex, while the smallest washers are most suitable against the rounded shaft of a long bone. No significant electrolytic reaction has been encountered in any of the patients treated by this method.

The C clamp has proved the answer to one previously unsolved problem in my experience—that of accurate fixation of fractures which include the large posterior lip of the lower portion of the tibia. In one such case the fragment subsequently slipped after final fixation by a wire-washer set alone. One or more Kirschner wires, drilled across the fracture site, have maintained reduction in other instances. The C clamp used as a drill guide permits one to place a wire-washer set exactly where one desires, while at the same time the clamp holds the fracture fragments in position until internal fixation is complete.

Adequate size of the flexible wire employed is of the utmost importance; the tendency is to use wire which is too light. For fixation of shaft fractures of the femur and tibia, circumferential loops and wire-washer sets should be of 18-gauge (approximately 0.049 inch in diameter) surgical stainless steel. Fixation of split femoral condyles and of large posterior-lip fractures of the lower portion of the tibia also requires wire-washer sets of this heavy wire. Wire-washer sets of 20 gauge (approximately 0.035 inch in diameter) generally suffice for fractures of the tibial plateau where lateral-displacement forces are usually less severe. Wire of 20 gauge is also adequate for the bones of the forearm and for the humeral shaft if applied to the best advantage.

Confusion between the numerical values for *gauge* and for *diameter* of flexible wire frequently occurs. One manufacturer of surgical wire even uses a third index of size, a wire *number* analogous to the common index of catgut or silk sutures. This confusion must be specifically guarded against when spools of wire are ordered. For instance, under the description of "size 20" wire, "20 thousandths" wire is often erroneously supplied instead of "20 gauge" wire. This wire, 0.020 inch in diameter, corresponds only to 25 gauge, which is much too light for use in the surgery of any major bone, and is too light for tightening and twisting by the instrument described in this report. Nothing smaller than 20-gauge stainless steel is recommended.

## SUMMARY

A wire tightener has been developed which tightens and then twists the ends of wire loops in a manner which is reproducible from loop to loop, and which does not place excessive strain on the basic twist where loops are liable to be weakened so that they subsequently break. Fifteen years of surgical experience have proved the dependability of this instrument and the value of its unique features. It provides strong and reliable fixation of bone fragments in a diversity of surgical procedures in which wire loops have the virtues of introducing a minimum of foreign material and of holding bone fragments in constant contact. The tightener is designed for use with 18-gauge and 20-gauge surgical stainless-steel wire, which sizes have been found most suitable for internal fixation of the major bones of the upper and lower extremities.

Two devices have also been developed which expand the field of usefulness of the tightener. The wire-washer set provides strong longitudinal fixation through a single drill hole in bone. The C clamp, with removable drill guide and special drill, aids in reducing certain fractures about major joints, and in holding the fragments securely during appropriate internal fixation. These two devices are of limited application but of great usefulness in specific situations.

# The Use of Small Bone Screws in the Treatment of Metacarpal, Metatarsal, and Phalangeal Fractures*

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Fractures of bones of the hand and foot follow a variety of patterns, dependent upon the mechanism of injury. Methods of treatment are nearly as numerous as the mechanisms of injury. Obviously, restoration of the severely crushed and shattered metacarpal or phalanx to a state approaching the normal anatomy may be impossible by any or all methods, and the compromise in such a case which will preserve any degree of useful function must be accepted. There are fractures, however, which are not beyond complete anatomical and functional restoration, but in which the result is compromised by failure to apply a proper technique or by inherent shortcomings of the technique used. The disability associated with volar displacement of the metacarpal head, prominent dorsal or plantar displacement of the metatarsal head, shortening or rotation of a metacarpal or metatarsal, and angulation with resulting prominences, is well known. In spite of meticulous application of various splints, traction methods, intramedullary fixation with Kirschner wire, and open reduction with circumferential wiring, the reduction and its maintenance is not always what one would desire.

As a result of these experiences, one of us (B.C.K.), working with Dr. W. F. Lyon in 1946, drew up specifications for small stainless-steel bone screws and plates. These, we believed, might be used in selected types of fractures with the probability of providing a more positive method of maintaining reduction, allowing (in the hand fractures) earlier mobilization of the fingers, and improved end results. No originality is claimed for the application of transfixion screws and plates in these small-bone fractures, but this report will relate the experimental and clinical experience we have accumulated.

## SCREW DESIGN AND CHARACTERISTICS

The selection of SMo 18–8 stainless steel was based on the relative non-electrolytic and the machining characteristics of this material. The use of a cylindrical rather than a tapered screw is a fundamental principle of bone repair, as is shown by the work of Sherman and more elaborately by Lyon, Cochran, and Smith in determining the actual holding power of screws in bone. The thread pitch and depth are considerations which affect the holding power of screws. Screws of the original design were abandoned because the fifty-six threads per inch were not cut deeply enough for an adequate cortical bite. The screws now used have thirty-six threads per inch and are more deeply grooved, obviating this objection. The present type will engage only one and one-ninth turns of thread in the average one thirty-second of an inch of thickness of cortical bone of the metacarpals and metatarsals, but the holding characteristics are definitely superior to those of more finely threaded screws (Fig. 1). Our tests indicated nearly double the holding power. The root diameter of the screw is .054 inch and the thread diameter is .090 inch. The screw can be passed through a No. 42 (.093 inch) drill hole without engaging, and holds well in either a No. 47 (.081 or five sixty-fourths of an inch) or a No. 48 (.078 inch) drill hole in cortical bone. This screw, so inserted, will not strip out easily with moderate pressure on the screwdriver. Bechtol has demonstrated that self-tapping flutes permit the safe insertion of bone screws into holes smaller than can be used for non-fluted screws without cracking the bone.

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* The screws and plates were manufactured and supplied through the cooperation and courtesy of the Zimmer Manufacturing Co., Warsaw, Indiana.

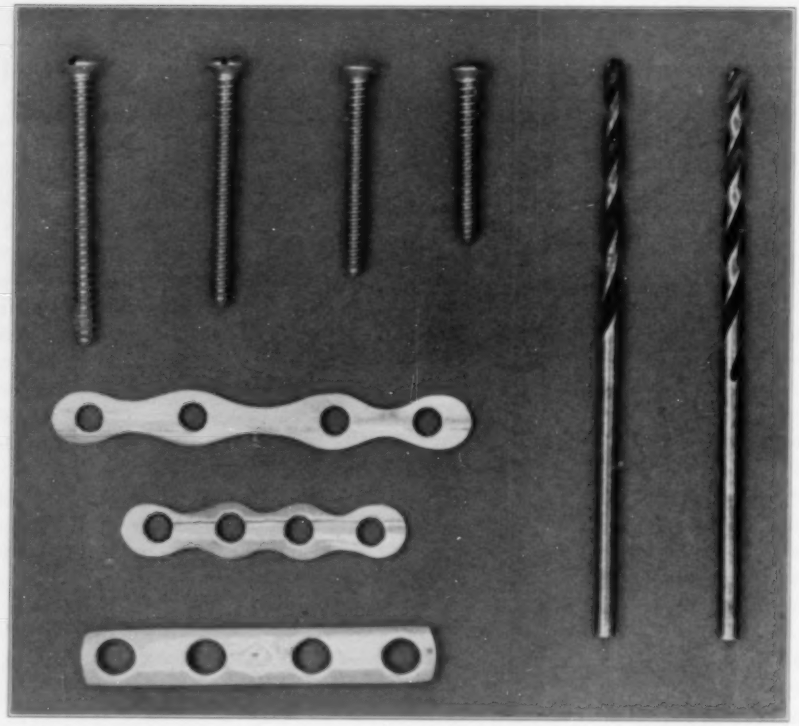

FIG. 1

Photograph showing screws, plates, and drills. These screws with an ovoid head and tapered neck can be countersunk to follow the contour of the cortical surface. Lengths from three-eighths to one inch are available. The No. 42 drill (far right) is used through the proximal cortex; the No. 47 drill (to the left), is used through the distal side of the cortex. The modified Lane plate design is shown in two varieties. Below them is the Zimmer type.

This results in greater holding power. Provision of flutes, however, will replace one-fourth to two-thirds of the circumference of the distal two threads of the screw, depending on whether the screw has one or two such flutes.

In using screws in the hand, we feel that in order to avoid soft-tissue irritation, the screw should not protrude more than one thirty-second of an inch beyond the distal cortex. To learn what effect flutes would have on actual holding power under these conditions, as well as to determine the range of holding power with varied drill sizes, seventy pulling experiments were carried out on cadaver metacarpals and fresh rabbit femora and tibiae. The results of twenty-one controlled tests are shown in Table I.

## TEST RESULTS

No screws split the bone as they were driven into the No. 47 holes. In all the tests on fresh bones, we did not split the bone with insertion of any of the screws into a No. 48 hole; even in a No. 49 hole, splitting did not occur, but it is very hard to start and turn a non-fluted screw in this size hole. This size also seemed too small for the fluted varieties. In the No. 49 hole, all screws frequently flaked out small superficial chips of bone at the edges of the hole as the screw emerged from the far side of the cortex. This occurred occasionally in the No. 48 holes. Our impression was that this flaking occurred more commonly with the fluted screws.

Analysis of the test shown in Table I revealed that, in relating holding power of the

TABLE I

| Test | Rabbit Bones | Clearance (*Inches*) | Screw Used | Pull (*Pounds*) | Holding Power Per 1/64 Inch of Cortical Bone (*Pounds*) | Drill Size (*No.*) | Cortical Thickness (*Inches*) | Bone Hardness (*Durometer Readings*) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Femur 1 | 1/32 | Non-fluted | 26 | 8.5 | 47 | 4/64 | 65 | |
| 2 | Femur 1 | 1/32 | 1 flute | 24.5 | 8.1 | 47 | 3/64 | 75 | |
| 3 | Femur 1 | 1/32 | 2 flutes | 20 | 6.6 | 47 | 3/64 | 75 | |
| 4 | Femur 2 | 1/32 | Non-fluted | 66 | 18.5 | 48 | 4/64 | 75 | |
| 5 | Femur 2 | 1/32 | 1 flute | 33 | 11 | 48 | 3/64 | 75 | |
| 6 | Femur 2 | 1/32 | 2 flutes | 32.5 | 10.8 | 48 | 3/64 | 70 | |
| 7 | Femur 3 | 1/32 | Non-fluted | 32 | 10.6 | 49 | 3/64 | 60 | |
| 8 | Femur 3 | 1/32 | 1 flute | 30 | 10 | 49 | 3/64 | 70 | |
| 9 | Femur 3 | 1/32 | 2 flutes | 40 | 13.3 | 49 | 3/64 | 75 | |
| 10 | Femur 4 | 1/32 | Non-fluted | 36.5 | 12.1 | 50 | 3/64 | 70 | Screw cracked out as it was turned in; bone fractured on pull |
| 11 | Femur 4 | 1/32 | 1 flute | 22.5 | 7.5 | 50 | 3/64 | 75 | Screw cracked to another hole on turning; bone fractured on pull |
| 12 | Femur 4 | 1/32 | 2 flutes | 25 | 8.3 | 50 | 3/64 | 70 | |
| 13 | Tibia 1 | 1/16 | Non-fluted | 46 | 15.3 | 47 | 3/64 | 70 | |
| 14 | Tibia 1 | 1/16 | 1 flute | 15.5 | 5.1 | 47 | 3/64 | 70 | Screw split into a crack made by previous test |
| 15 | Tibia 1 | 1/16 | 2 flutes | 32 | 10.6 | 47 | 3/64 | 68 | Screw split into previous hole |
| 16 | Tibia 2 | 1/16 | Non-fluted | 47 | 15.6 | 48 | 3/64 | 65 | |
| 17 | Tibia 2 | 1/16 | 1 flute | 33.5 | 8.3 | 48 | 4/64 | 70 | |
| 18 | Tibia 2 | 1/16 | 2 flutes | 46 | 15.3 | 48 | 3/64 | 70 | |
| 19 | Tibia 3 | 1/16 | Non-fluted | 40 | 10 | 49 | 4/64 | 75 | |
| 20 | Tibia 3 | 1/16 | 1 flute | 65 | 16.2 | 49 | 4/64 | 70 | |
| 21 | Tibia 3 | 1/16 | 2 flutes | 48 | 12 | 49 | 4/64 | 70 | |

TABLE II

| No. of Specimens | Bone Hardness (*Durometer Reading*) | Average Holding Power Per 1/64 Inch Cortical Thickness (*Pounds*) |
|---|---|---|
| 1 | 60 | 10.6 |
| 2 | 65 | 11.5 |
| 10 | 70 | 11.9 |
| 8 | 75 | 11.9 |

screws to the presence of flutes (excluding tests Nos. 10 through 15), screws with no flutes had holding power of 12.6 pounds per one sixty-fourth of an inch of cortical thickness. Screws with one flute had 10.7 pounds of holding power, and those with two flutes a holding power of 11.6 pounds per one sixty-fourth of an inch of cortical thickness.

In comparing holding power with drill size (excluding test No. 14), it was found that the No. 47 drill hole had a holding power of 9.8 pounds per one sixty-fourth of an inch of cortical thickness; No. 48, a holding power of 11.9 pounds; and No. 49 had a holding power of 12.0 pounds per one sixty-fourth of an inch of cortical thickness.

Analysis of holding power according to the distance of protrusion of the screw beyond the far side of the cortex (including all types of bone and Nos. 47, 48, and 49 drills; excluding Test No. 14) showed that protrusion of one thirty-second of an inch was related to a holding power of 10.5 pounds, and one-sixteenth of an inch to 12.6 pounds.

Results of studies relating bone hardness to the average holding power are shown in Table II.

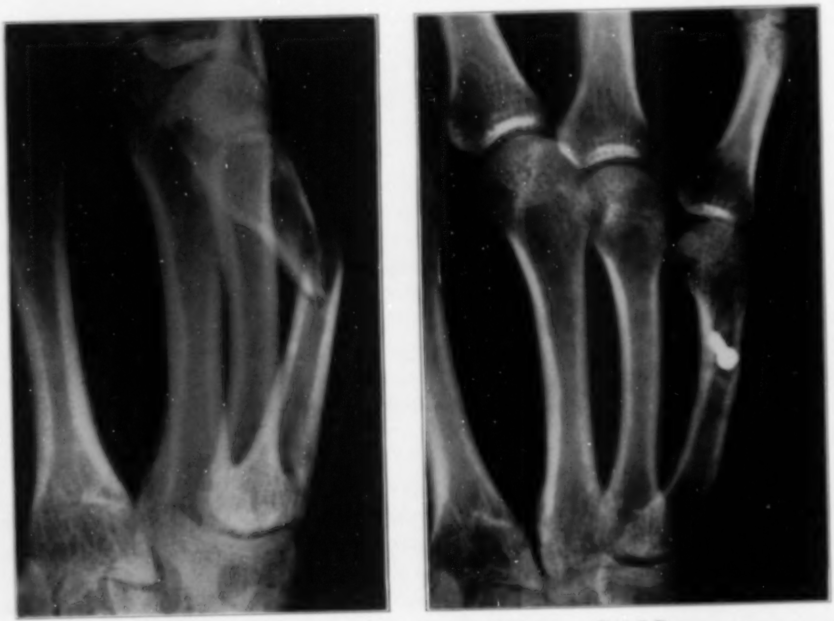

Fig. 2-A

Fig. 2-B

Roentgenograms of an oblique fracture of the right fifth metacarpal in a man twenty-nine years old. The fracture was reduced and the hand put in a cast elsewhere one week previously. Reduction was not maintained. Treatment by open reduction and transfixion screw led to union in anatomical position.

TABLE III

| Case | Location of Fracture | Type of Fracture and Associated Injury | Treatment of Fracture | Result |
|---|---|---|---|---|
| 1 | 5th metacarpal | Closed; oblique over-riding at distal end of shaft | Previously closed reduction and cast; open reduction and transfixion screw | Excellent |
| 2 | 5th metacarpal | Closed; oblique over-riding at distal end of shaft | Open reduction; transfixion screw | Excellent |
| 3 | 3rd metacarpal | Open; comminuted at distal end of shaft; flexor tendon severed | Immediate reduction and transfixion screw; subsequent flexor-tendon graft | Good |
| 4 | 3rd metacarpal | Closed; spiral oblique with over-riding of both fractures | Open reduction; transfixion screws to each fracture | Excellent |
| 5 | 2nd metacarpal | Comminuted at distal end of shaft and head | Open reduction and plate | Fair |
| 6 | 2nd metacarpal | Closed; unstable; oblique fracture | Traction failed; open reduction; transfixion screw | Excellent |
| 7 | 3rd metacarpal | Malunion with angulation and rotation | Osteotomy; plate; transfixion screw | Excellent |
| 8 | 1st metatarsal | Closed; oblique over-riding at distal end of shaft; dorsal displacement of distal fragment and head | Open reduction; transfixion | Excellent |
| 9 | Proximal phalanx of thumb | Open; oblique; over-riding; severed extensor tendon | Transfixion screw; extensor tendon repaired | Good |
| 10 | Proximal phalanx of thumb | Oblique, into distal end of joint; distal phalanx crushed; extensor tendon avulsed | Transfixion screw; soft-tissue repair | Circulatory failure; loss of distal phalanx |
| 11 | Proximal phalanx, middle finger | Open; comminuted; displaced | Transfixion screw; soft-tissue repair | Good union; poor function |
| 12 | Proximal phalanx, middle finger | Open; comminuted; displaced | Transfixion screw; circumferential wiring | Good union; fair function |
| 13 | Proximal phalanx, index finger | Oblique; extensive soft-tissue laceration; questionable viability | Transfixion screw; soft-tissue repair | Gangrene; amputation |
| 14 | Middle phalanx, middle finger | Oblique; displaced | Could not be held by traction; open reduction; transfixion screw | Fine-thread screw insufficiently engaged; pulled out at second operation, fragments held with intramedullary wire; fair result |
| 15 | Middle phalanx, middle finger | Oblique; extensive laceration | Transfixion screw | Good union; function poor |

## COMMENTS

One notes in the test results a slight superiority of holding power for the non-fluted screws. This is more evident when the clearance of protrusion was one thirty-second of an inch and diminished as the screws were projected one-sixteenth of an inch. As previously theorized, we feel this is due to the partial loss (by fluting) of the distal two threads which

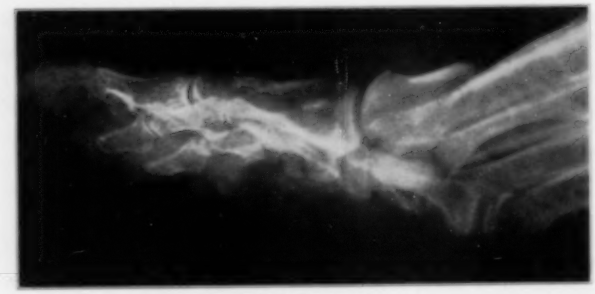

FIG. 3-A

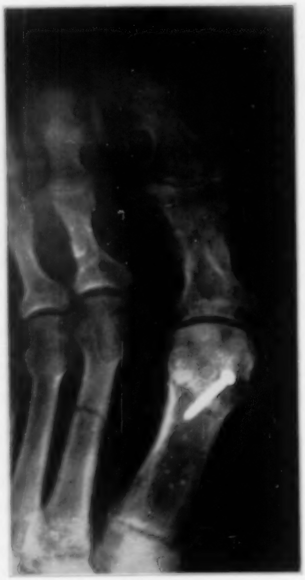

FIG. 3-C

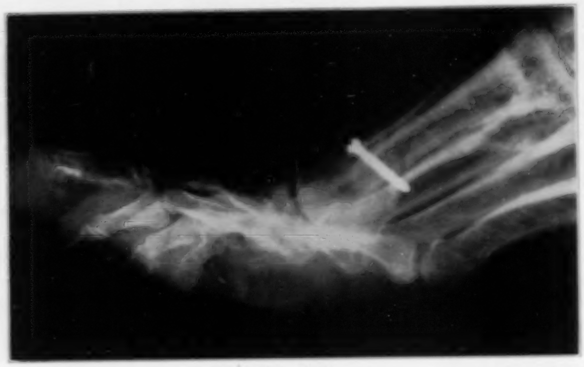

FIG. 3-B

Fig. 3-A: Lateral view shows the displaced fragments of a first metatarsal fracture which occurred when a heavy object struck this man's foot. Primary open reduction with screw transfixion was carried out.

Fig. 3-B: The lateral projection after six weeks shows accurate reduction.

Fig. 3-C: The anteroposterior view allows comparison of the rate of bone healing (as disclosed by roentgenogram) with the transverse fracture of the second metatarsal shaft which was not exposed or disturbed by our procedure. This undisplaced fracture is more distinctly visible than is the transfixed oblique first metatarsal fracture.

occupy the last one-sixteenth inch of the screw. Our tests are too few to be absolutely certain of this point; but, because of the logic of the assumption and the results, we have chosen to omit the flutes. We feel this would not be justified in larger screws for use in other long bones where protrusion is not objectionable and added holding power so important.

We have recommended a No. 47 drill size for the distal cortex in spite of inferior holding power in order to lessen the risk of splitting the bone. It is our belief that the pull required will adequately withstand forces applied in these small-bone fractures. Should the No. 48 size be found clinically suitable, as in relatively soft cortical bone, it may be used.

An ovoid head with a tapered neck seemed to conform best to the contour of the cortical surface through the range of angles required. It is desirable to countersink the head. Screw lengths vary from three-eighths to one inch, graduated by eighth-inch increments.

## BONE PLATES

Two varieties of plates are manufactured. One type is a modified Lane design; the other is a Zimmer type. The former would seem to be heavy enough for most metacarpals in which a plate might be indicated. The Zimmer type is a little thicker and seems to project above the surface more than is desirable. Although the indications for the use of a plate (Case 5) may be rare, availability of a suitable design is desirable should the need arise.

## TECHNIQUE

The metacarpal fracture is exposed in a bloodless field through a vertical incision placed to one side of the metacarpal on the dorsum of the hand. When two metacarpals are to be exposed, a single skin incision between the two will be adequate. The incision is deepened down to and through the periosteum, disturbing the extensor tendons as little as possible. With a small dissector, the periosteum and interossei dorsales attachments are reflected sufficiently to allow reduction of the fracture and introduction of a suitable forceps or bone clamp. The direction of the proposed drill hole is noted while the fracture is held in reduction. A No. 42 drill is used through the proximal side of the cortex, and a No. 47 or No. 48 through the opposite side of the cortex. To start the drill in the line selected, it may be necessary to gouge a small notch in the cortex to prevent the drill from slipping. The hole through the opposite side of the cortex must be accurately aligned with the proximal drill hole, or reduction will be compromised. In dealing with a short oblique fracture near the head of the metacarpal, it may be necessary to mark the opposite side of the cortex with the drill while the fracture is reduced, then displace the superficial fragment and hold the deeper fragment more firmly while the drilling is completed. If the fracture is long, oblique, or spiral, a bone-holding clamp or a small Kocher forceps may be of great help. A countersinking instrument will provide a recess for the screw head when the screw is inserted in an oblique direction. The Bunnell hand drill, or any similar twist drill which will bring the operator close enough for accurate control, has been found satisfactory. The screw should extend completely through the far side of the cortex, but protrusion beyond one thirty-second of an inch is to be avoided.

Wound closure is carried out by use of fine cotton (No. 60 or 100) to the subcutaneous layers, and fine dermalon to the skin. The corresponding digit is then immobilized upon a light aluminum splint in a relaxed, semiflexed position. Splinting is maintained for from two to four weeks, depending upon the stability of fixation as judged at operation. Active use of the finger is then encouraged, but passive stretching and heavy work are avoided until the progress toward union is deemed sufficient by roentgenographic evidence.

The approach to a proximal or middle phalangeal fracture is made through a dorsolateral or mid-lateral incision. Splinting is essentially the same as described for the metacarpal, or as indicated by the demands of the extensor-tendon repair, if it is done simultaneously. A dorsal incision is used for the metatarsal fracture and after-care of the fractured foot will follow the principles used in treatment of wounds and fractures at this site by other methods.

## CLINICAL EXPERIENCE

Our experience consists in the use of transfixion screws in fourteen fractures; a metacarpal plate was used twice. The location, type of injury, treatment, and results are shown in Table III.

In general, it will be seen that the use of the single transfixion screw in oblique or spiral displaced fractures of the metacarpals and of the important first metatarsal bones led to very satisfactory results. In these cases, as is shown in Figures 2-A through 3-C, the reductions were anatomical, bone healing progressed satisfactorily, and the functional results were very good. It is of interest in Figure 3-C to note there was less absorption at the transfixed first metatarsal fracture line in six weeks than was present in the undisplaced second metatarsal fracture, which was not exposed. Both fractures progressed to complete union as shown in a later roentgenogram. The comminuted fracture generally should not be treated by this method, although the result in Figure 4-B is acceptable.

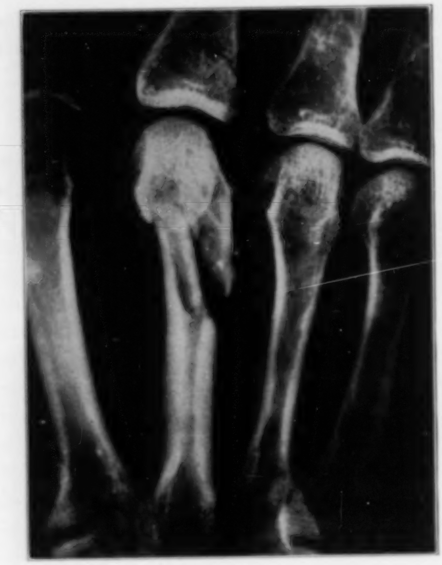

FIG. 4-A

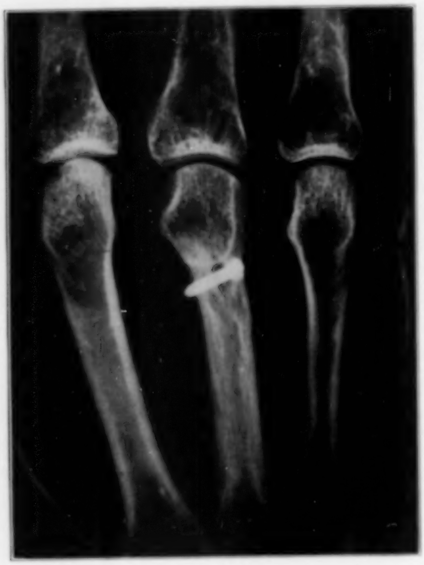

FIG. 4-B

Fig. 4-A: This comminuted fracture of the third metacarpal was associated with division of the corresponding flexor tendons. Primary screw fixation of the fracture resulted in union.

Fig. 4-B: Nine weeks later the tendons were replaced with a graft. Good function was obtained.

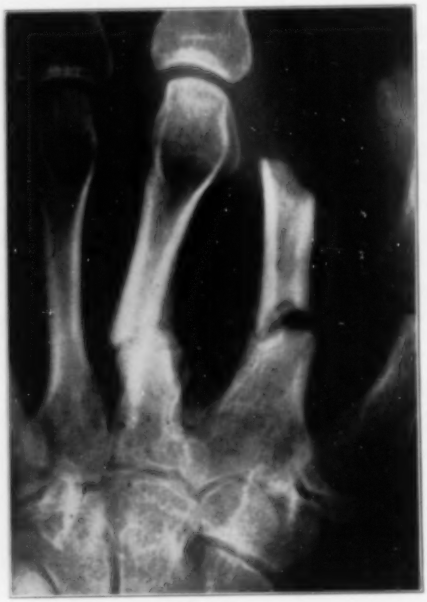

FIG. 5-A

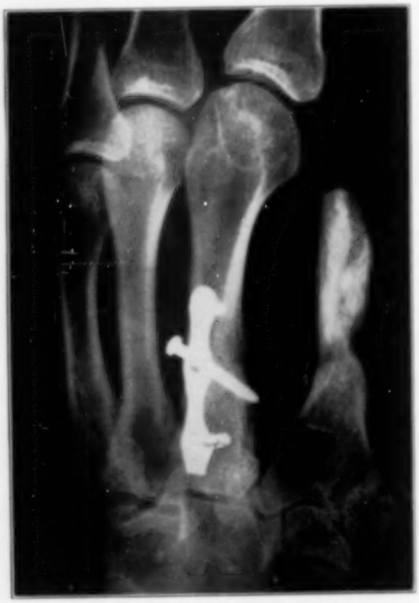

FIG. 5-B

Fig. 5-A: Following punch-press injuries nine months earlier, which resulted in loss of the distal phalanges of the thumb and the index finger, the malunion of the fractured third metacarpal prohibited opposition of the middle finger to the stump of the thumb. An oblique osteotomy was performed; the metacarpal was shaped, rotated, and held firmly by the small plate and transfixion screw.

Fig. 5-B: Union was obtained and excellent function resulted.

The use of transfixion screws in the fingers should probably be limited to the proximal phalanges, and even in this area to the oblique displaced fracture near the base, which is difficult to control by other methods. The degree of stabilization obtained in two of our patients made it possible for us to carry out extensor-tendon repair simultaneously, with one satisfactory result. The unsatisfactory result in the other cannot be attributed to the method, but rather to the damaged circulation which finally resulted in loss of the distal phalanx.

In the event of a fracture and a severed flexor tendon, it is advisable to initiate fracture healing as promptly as possible, mobilize the joints by passive exercise, and to proceed with tendon repair or grafting as a secondary procedure.

Treatment by the transfixion screw is not suitable for fractures of the middle phalanges. Because of the relatively small size of these bones, their shapes, and relationships to the tendons, the operative exposure necessary for the procedure may contribute to subsequent scarring and stiffness in spite of successful reduction of the fracture. Should the fracture be associated with extensive lacerations, the exposure may be provided by the injury, but the result no less disastrous. We are more inclined to favor external splinting, where applicable, or the use of intramedullary Kirschner wires if necessary.

A warning against indiscriminate use of this procedure is appropriate. It cannot be expected to replace all forms of hand-fracture therapy. The technique should be precise. Use of heavy bone-crushing clamps should be avoided, and great care taken to drill holes no larger than recommended. The screws should be set with firmness but with respect for the relatively thin cortical bone with which we are dealing. Rough methods can be more disastrous than the fracture untreated.

## CONCLUSIONS

1. The use of small stainless-steel bone screws for maintenance of reduction of selected oblique and spiral fractures of the hand and foot has, in our experience, been justified by the results obtained.

2. When properly applied, the technique can lead to results superior to those of other methods of treatment.

3. There appear to be few indications for the use of small plates.

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# A Method of Fusion of the Metatarsophalangeal Joint of the Great Toe

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Osteo-arthritis of the first metatarsophalangeal joint (hallux rigidus) is a very painful and disabling condition. When present it limits the patient's ability to walk. Treatment in mild cases can be conservative. This consists in rest and the use of a metatarsal bar and a steel shank in the sole of the shoe. If the condition is severe enough to require operative intervention, various arthroplasties have been done. These give a good result in older people or in persons not on their feet all the time. Arthrodesis gives a painless foot which will allow either long-continued standing or walking. The purpose of this paper is to describe a method of fusion which will produce arthrodesis in six to eight weeks. Standard methods of fusion require at least four months, or attack the plantar weight-bearing surface of the toe, as in McKeever's method.

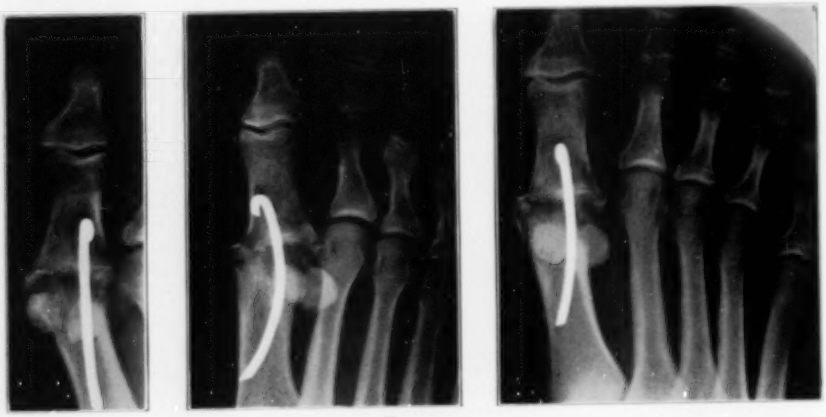

Fig. 1

Roentgenograms showing fusion of the metatarsophalangeal joint of the great toe in six weeks.

The method used is to make a dorsal incision about one and a half inches long over the first metatarsophalangeal joint medial to the extensor hallucis longus tendon. The joint is then exposed; the articular cartilage is removed and raw cancellous bone is exposed. An oscillating motor saw is useful for the mobile proximal phalanx. The bone surfaces must be cut so as to allow 15 degrees of dorsiflexion of the arthrodesed joint. The surfaces must also be flat to allow maximum bone contact. Too much dorsiflexion of the proximal phalanx will cause excessive prominence of the interphalangeal joint. This will cause rubbing on the shoe and give a painful callus. Of course, if high-heeled shoes are to be worn, the angle of dorsiflexion of the arthrodesed joint must be increased.

The factor which gives the rapid bone union is compression [1]. This is obtained by means of an intramedullary Rush nail which has been curved to suit the required angle. The curve can be easily fashioned with two pairs of pliers. A smooth curve is essential or else it will be found difficult to drive an angled nail around the curve.

A path for the nail is made in the proximal phalanx by a drill point which is larger than the nail. The path starts on the dorsum of the proximal phalanx, about three-eighths to one-half inch distal to the cut edge and is brought out in the center of the raw cancellous bone. A starting point is made in the center of the metatarsal head. This hole is

TABLE I

| Case | Date of Fusion | Time of Walking (*Days*) | Follow-up | Result | Complications |
|---|---|---|---|---|---|
| 1. | May 1954 | 42 | 3½ years | Good | None |
| 2. | June 1955 | 42 | 2 years | Good | None |
| 3. | Sept. 1954 | 49 | 3 years | Good | None |
| 4. | Mar. 1955 | 42 | 2½ years | Good | None |
| 5. Rt. | Jan. 1957 | 56 | 9 months | Good | None |
| Lt. | Jan. 1957 | 56 | 9 months | Good | None |
| 6. | Mar. 1957 | 42 | 7 months | Good | Foot swelled for 3 months |
| 7. | Aug. 1956 | 86 | 14 months | Good | Nail fractured base of proximal phalanx; point of nail protruded through shaft of metatarsal |
| 8. | Feb. 1954 | 56 | 3½ years | Good | None |
| 9. | Mar. 1954 | 56 | 3½ years | Good | None |

smaller than the nail and is used as a starting point only. The size of these two holes is important. The distal hole is large so that the phalanx can be brought against the metatarsal head easily. The handle of the Rush nail provides the firm fixation needed. The cancellous bone of the metatarsal grips the shaft of the nail; it is important that it not be drilled too much or the required fixation will be lost. When the nail has been driven home with the Rush driver, the two bones are fastened together surprisingly firmly. A below-the-knee plaster cast is applied which includes the great toe. This cannot be a walking plaster.

## RESULTS

This method has been used in ten toe fusions. In one patient the procedure was bilateral. The plaster cast was removed in six to eight weeks in all patients except the seventh, in whom the nail fractured the ridge of bone which holds the handle of the Rush nail. There was good position afterward but there was no compressing force. The patients started to walk as soon as the cast was removed with very little difficulty. Only in the sixth patient was there any excessive swelling. This gradually disappeared in three months with the use of an arch support and an elastic stocking. In one patient the nail protruded through the cortex of the first metatarsal on the dorsal aspect. This caused a painful bursa and the sharp point had to be removed one year later.The area of fusion was visualized at the second operation. No line of demarcation between the phalanx and the metatarsal could be seen—the bone surface was continuous. The head of the nail was covered with cortical bone and was not seen. The results are listed as good in all patients because they can walk and stand without discomfort. There were no wound infections. It has not been necessary to remove the nail in any patient, except the point of one (Table I).

## DISCUSSION

It is felt that compression is the factor which allows the rapid arthrodesis. This was illustrated by the seventh patient in whom there was immobilization but no compression because the handle of the nail broke the ridge of bone on the proximal phalanx. Thus the means by which the nail compresses the proximal phalanx against the metatarsal head was lost. In this patient fusion became solid in eighty-six days.

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# Recurrent Dislocation of the Patella in the Adult

## End Results of Patellectomy with Quadricepsplasty *

BY FRANCIS E. WEST, M.D., SAN DIEGO, AND RALPH SOTO-HALL, M.D., SAN FRANCISCO, CALIFORNIA

The pathomechanics of recurrent dislocation of the patella has been fully described in the literature. The laxity of the medial capsule [14], the valgus knee [1], the flat articular femoral condyle [2], abnormalities of the position, shape, and size of the patella [15, 17, 18, 19, 20, 23, 24, 25, 26] and the occasional shifting in the insertion of the patellar tendon [10, 11, 12] have all had procedures designed to correct or remedy the deformity [5, 6, 7, 8, 13, 21, 22]. The majority of these operations have rectified the dislocation of the patella but have failed to attack the intra-articular problems which, we believe, occur as residual changes following the original deformity. There also has been a noticeable failure to differentiate between the pathological changes seen in childhood and those seen in later life. Our discussion, with one exception, is concerned only with those cases in which the recurrent or chronic dislocation is present in the adult. The history of an eleven-year-old girl is included in our study because, after several operative failures in both knees, patellectomy was successful.

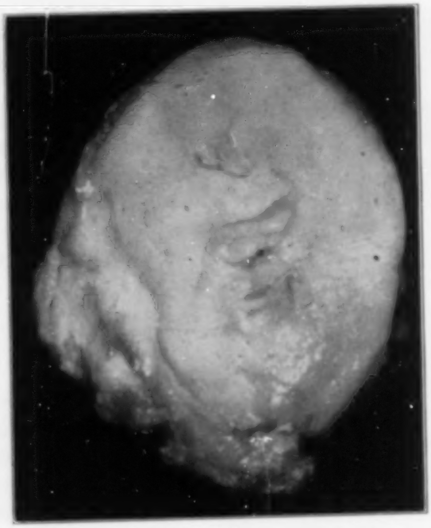

FIG. 1-A

Chondromalacia.

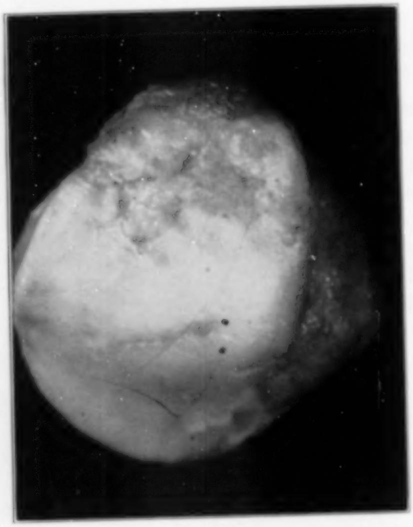

FIG. 1-B

Chondromalacia with polished surface.

Recurrent dislocation of the patella in the adult generally presents severe degenerative changes in the articular cartilage of the patella, and not infrequently presents so-called mirror-image changes in the lateral condyle of the femur and chondromalacia (Figs. 1-A and 1-B). When dislocation of the patella was corrected by any of the described operations such as capsuloplasty, fascial transplants [9], transplantations of the patellar tendon, or osteotomy, a high percentage of late poor results was encountered because mechanical arthritis of the patellofemoral joint developed after a number of years [3, 4, 16]. These changes came from chondromalacia and distortion of the patella. On being restored

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* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 31, 1957.

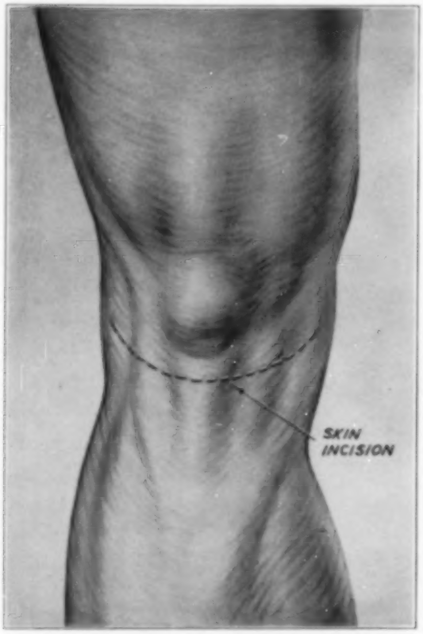

FIG. 2
Skin incision.

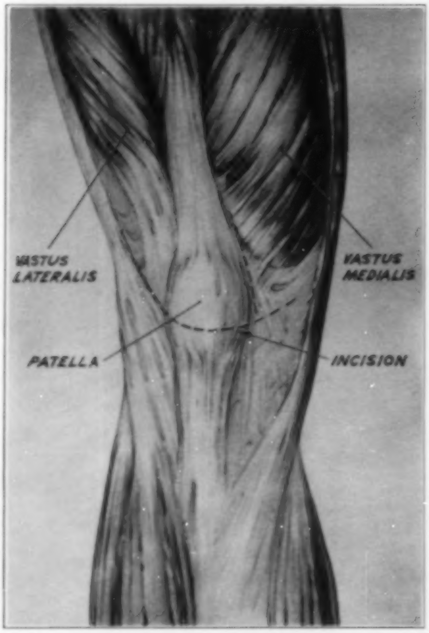

FIG. 3
Capsule incision, dissection of vastus medialis muscle.

to the intercondylar groove, the friction of incongruous surfaces produced irritation.

Patellectomy without quadricepsplasty is an illogical procedure because abnormal mechanics persist and recurrent dislocation of the tendon may result.

We are unable to give either the exact age at which irreparable changes may develop in the patella, or how long subluxation must be present before chondromalacia develops. In our series of twenty patients (twenty-four operations), all but one showed advanced degenerative changes of the articular cartilage.

Recurrent dislocation of the patella results from congenital, developmental, or traumatic factors, or from a combination of these. In the present series, seventeen knees had symptoms considered to be congenital; six, traumatic; and one, unknown. Surgical findings showed four instances of mirror-image changes in the femoral condyle and five instances of loose bodies. Dislocation may be present in childhood or may manifest itself clinically in adult life. The patella may merely subluxate or may present chronic lateral displacement. We have treated both types in this series. In an effort to correct the anatomical deformities and at the same time to eliminate the hazards of patellofemoral arthritis, a new operative procedure was devised by the authors which has been used on twenty patients with a total of twenty-four operations.

The patients ranged in age from eleven to sixty-two years with symptoms present from four to forty years. There were twelve females and eight males. Bilateral operations were performed in four; although the disease was bilateral in several others, the symptoms did not warrant surgical repair.

## SURGICAL PROCEDURE

The operation is performed in a bloodless field obtained with the use of a tourniquet. The patella is approached by a cup-shaped incision (Fig. 2), the center of which passes just below the patella. The quadriceps expansion is incised also in the same manner so

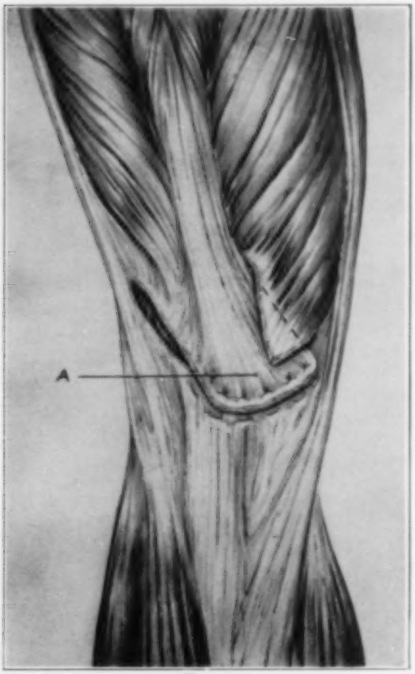

Fig. 4
Capsuloplasty.

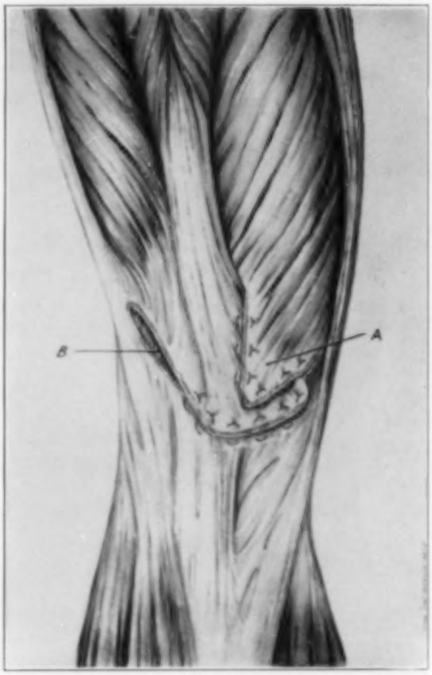

Fig. 5
Resuture of vastus medialis muscle.

that the incision passes over the level of the inferior third of the knee cap (Fig. 3). This tends to bring the suture line of the tendon into the area of the fat pad rather than into the line of the femoral condyles. The quadriceps tendon is carefully removed from the patella by meticulous sharp dissection.

The joint is carefully inspected. Loose bodies are removed and, if the femoral condyle presents an area of either polished surface or chondromalacia, the area of diseased cartilage is beveled by sharp dissection. Small drill holes are placed where subchondral bone is exposed so that fibrocartilage may form.

The capsule is then drawn distally to overlap about one-half inch in order to restore proper tendon tension. It should be displaced medially from one-half to three-fourths of an inch (Fig. 4). The height of the patella should be studied in preoperative roentgenograms in order to determine the correct distance of distal overlapping. The shifting of the quadriceps medially leaves a gap in the capsule laterally which should be left unsutured. The synovial membrane should be closed if it can be easily approximated. The vastus medialis muscle, which has been sectioned at its insertion and forms a V-shaped mass, is then transferred distally and laterally (Fig. 5). This will result in the muscle's partially covering the defect at the previous site of the patella. If reattached in this manner, contraction of the vastus medialis will tend to bring the capsule medially. After repair, the knee should be tested so that flexion to 90 degrees without undue tension of the sutures can occur. Absorbable interrupted sutures are used, and the subcutaneous tissue and skin are closed in the usual manner after removal of the tourniquet.

## POSTOPERATIVE CARE

A toe-to-groin plaster splint is applied and quadriceps exercises are begun within forty-eight hours. Patients may be allowed to walk with crutches after seven to ten days.

At the end of three weeks the splint is made removable so that active exercises and

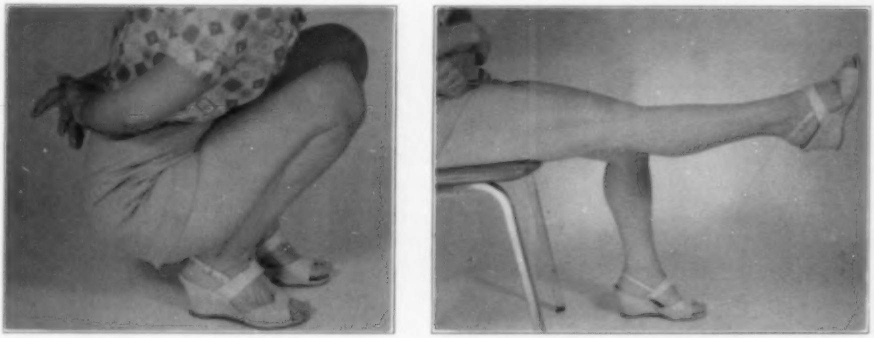

FIG. 6

Case 2: End result of patellectomy with capsuloplasty. (The range of flexion was computed from an angle of 180 degrees—full extension—to a residual angle, the normal being considered 35 degrees. The data in the case reports and Table I are based on this method of measurement.)

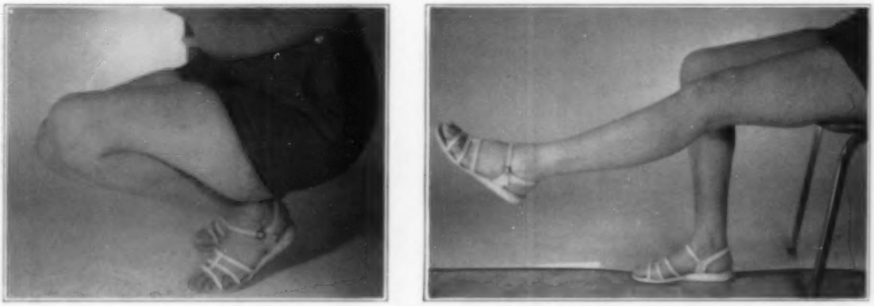

FIG. 7

Case 4. End result of patellectomy with capsuloplasty.

motion may be begun. It is customary to remove all support after five to six weeks. Progressive resistance exercises of the quadriceps are begun after the fifth week.

Full extension of the knee usually is not obtained for some weeks and it may not be obtained for as long as five to six months in some patients. Full flexion usually returns within eight to ten weeks (Figs. 6 and 7) (Table I).

## RESULTS

In this series of twenty patients, all have resumed their normal activities. Of the twenty-two patellectomies with quadricepsplasty, results were excellent in fifteen, good in six, and poor in one. By an excellent result we mean full painless motion, resumption of normal activities, and good quadriceps power. Two of the patients with excellent results had some loss of flexion; these will be discussed in detail later. In a good result, there is normal painless motion, and the patient has resumed normal activities, but there may be some residual weakness in the quadriceps power. This power may yet be improved with further supervised resistive exercises.

There has been only one patient in whom the result was less than good. In this patient, extension is possible to within 10 degrees of full extension, and there is a loss of 10 degrees of flexion. There is weakness in the quadriceps and mild subjective pain. One boy, two years after this procedure, played baseball at college; another young man who had had a bilateral procedure was able to dive from a springboard and engage in water skiing.

Three patients have mild residual restriction in flexion. However, each of them had

TABLE I

Twenty-Four Cases of Recurrent Dislocation of the Patella

| Case | Patient | Side | Age (*Years*) | Sex | Duration and Cause | Previous Treatment | Date of Surgery | Surgical Findings | Complications | Results |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | R.S. | L | 22 | M | 3 years, probably traumatic | Supportive | 1944 | Marked changes with loose bodies and mirror-image changes in femoral condyles | None | Excellent; extension, 180 degrees; flexion, 35 degrees; full activity (see Fig. 6) |
| 2. | R.U. | R | 31 | F | Since childhood, probably congenital | Casts, exercises | 1944 | Chondromalacia, severe, with mirror-image changes in femoral condyles | None | Excellent; extension, 180 degrees; flexion, 35 degrees; full activity; has trouble with other knee; should have patellectomy on left |
| 3. | M.A | L | 62 | M | 40 years, traumatic | None | 1947 | Severe osteo-arthritis of patella, paracapsular bone | None | Excellent; extension, 180 degrees; flexion, 70 degrees; able to return to work without symptoms |
| 4. | V.F. | L | 35 | F | Many years, congenital | Casts, strapping, exercises | 1952 | Chondromalacia | None | Excellent; extension, 180 degrees; flexion, 35 degrees; full activity; no complaints |
| 5. | B.L. | L | 20 | F | Congenital | Support and exercises | 1949 | Chondromalacia, severe | None | Good; full motion; some weakness in knee; needs exercises |
| 6. & 7. | L.Mc. | Bilateral | 16 | M | 9 years, congenital | Supports | Left: Apr. 1952<br>Right: Sept. 1952 | Left: chronic loose bodies<br>Right: chondromalacia | None | Excellent; full motion; extension, 180 degrees; flexion, 35 degrees; can water ski and dive |
| 8. & 9. | S.G. | Bilateral | 17 | F | Congenital | Plicating operation right, unsuccessful | Left: Sept. 1952<br>Right: Nov. 1952 | Chondromalacia, severe, bilaterally | | Left good but weak; needs exercises; right, excellent; full motion |
| 10. | M.G. | R | 41 | M | Since 1952, traumatic | Patellectomy for fracture, developed dislocating tendon | July 1953, quadricepsplasty | Tendoplasty as patella had been removed | Secondary infection and drainage | Excellent; extension, 180 degrees; flexion, 35 degrees; no subjective complaints; regular employment |
| 11. | B.D. | R | 27 | F | 20 years, congenital | Left patellectomy, 1949 | March 1955 | Chondromalacia, severe | Fell during convalescence; hemorrhagic effusion | Excellent; extension, 180 degrees; flexion, 35 degrees; slight weakness; improving with exercises |
| 12. & 13. | C.S.B. | Bilateral | 11 | F | Many years, congenital | Unsuccessful repair, left knee, 1952 | Left: quadricepsplasty, March 1955<br>Right: patellectomy, Aug. 1955 | Minimal cartilaginous changes, left only | None | Excellent; full motion, both knees |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Left: patellectomy, Dec. 1955 | | | |
| 14. & 15. | B.M. | Bilateral | 22 | F | Left: 10 years<br>Right: 16 years, congenital | Supportive | Left: June 1955<br>Right: July 1955 | Left: chondromalacia with mirror-image changes in femoral condyles<br>Right: chondromalacia | None | Good; extension, 180 degrees; flexion, 35 degrees<br>Good; extension, 180 degrees; flexion, 35 degrees; both knees weak on stairs; needs exercises |
| 16. | A.R. | R | 37 | F | 25 years, probably traumatic; patient had poliomyelitis, right arm and left leg affected | Supportive | Feb. 1955 | Chondromalacia, severe | Phlebothrombosis of right leg one month later | Poor; extension, 170 degrees; flexion, 45 degrees; falls frequently |
| 17. | J.B. | L | 22 | F | 6 years, congenital | Supportive | Quadricepsplasty, Aug. 1955 | Chondromalacia, mild | Crepitus under knee cap | Good; full motion; extension, 180 degrees; flexion, 35 degrees; no pain |
| 18. | E.M. | L | 25 | M | 4 years, traumatic | Reduced and supportive | Jan. 1956 | Chondromalacia. severe loose bodies | None | Good; extension, 175 degrees; flexion, 35 degrees; mild thigh atrophy; doing regular work, but weak; should improve |
| 19. | D.L. | R | 20 | M | Unknown | Supportive | July 1956 | Chondromalacia, with one loose body | None | Excellent; extension, 180 degrees; flexion, 40 degrees; can go to full squat and return; regular activities |
| 20. | B.W. | L | 26 | F | Many years; 2 years acute; minor injury; hypermobile; probably congenital | 1947, medial meniscectomy<br>1948, lateral meniscectomy | Apr. 1949 | Chondromalacia, advanced; obliterated suprapatellar pouch | None | Excellent; extension, 180 degrees; flexion, 70 degrees; slightly unstable and weak |
| 21. | M.U. | R | 22 | F | Over 10 years, congenital | Conservative | June 1946 | Chondromalacia, loose bodies; patella with mirror-image changes in femoral condyles | None | Excellent; normal range of motion after one year |
| 22. | G.A. | L | 43 | F | 20 years, congenital | Conservative | May 1949 | Deformed patella and chondromalacia | | Excellent |
| 23. | Sister A. | R | 45 | F | 4 years, congenital and traumatic | Conservative | Jan. 1950 | Chondromalacia, severe | | Excellent; some pain, but normal range of motion |
| 24. | E.D. | L | 16 | M | 6 years, traumatic | Conservative | Aug. 1955 | Chondromalacia, severe | None | Excellent; full range of motion; plays college baseball |

other defects prior to surgery and the end results in two of these patients are considered to be excellent. The third is classified as poor. These patients deserve further discussion.

Case 20. B. W., a young woman, had had two previous surgical procedures on the left knee with resultant obliteration of the suprapatellar joint space and limited motion in extension of about 170 degrees as compared with 180 on the opposite side. She had flexion to 110 degrees compared with 35 degrees in her right knee. The knee was unstable and the patella subluxated laterally. The patient was willing to have arthrodesis performed. Patellectomy and quadricepsplasty were accomplished in 1949. At the present time the patient works regularly and has had no further dislocation. Motion in both knees in extension is 180 degrees, and in flexion, 70 degrees on the left, and 35 degrees on the right. The knee is not perfect, but is functionally excellent eight years after surgery.

Case 3. M. A., a man, sixty-two years old, was unable to work because of pain and limited motion in his left knee. The symptoms had been progressive for the previous forty years. He had an unreduced lateral dislocation of the patella. His preoperative motion in extension was 145 degrees on the left side compared with 180 degrees on the right side. Flexion on the left side was to 90 degrees compared with 35 degrees on the right. Patellectomy and quadricepsplasty were performed in 1947. He was a manual laborer for nine years after the operation without complaint. The motion of both knees at the time of writing was 180 degrees of extension; flexion was possible in the left knee to 70 degrees compared with 35 degrees on the opposite side. There was excellent power in the quadriceps.

Case 16. A. R., a woman, thirty-seven years old, had a history of recurrent dislocation of the right patella for the previous twenty-five years. In addition, she had residual changes following poliomyelitis with a surgical ankylosis of the right shoulder, and moderate involvement of the left lower extremity. Patellectomy and quadricepsplasty were performed on February 24, 1955, and marked chondromalacia was found. This procedure was followed by a moderately severe phlebothrombosis of the right leg. The patient responded to novocain injections of the paralumbar sympathetic system. Subsequently, she had several falls and physical-therapy treatment was poorly supervised. The patient later proved to be a chronic alcoholic. We have classified the results obtained as poor. Extension was possible to 170 degrees in the right knee compared with 180 degrees in the left knee; flexion was possible to 45 degrees in the right knee compared with 35 degrees in the other. There was subjective pain and weakness. The patient walked with a cane in order to avoid falls.

Case 12. C. S. B., an eleven-year-old girl, had previously had a capsuloplasty done elsewhere on the left knee with failure. She was reoperated upon on March 11, 1955, but because of her age a quadricepsplasty without patellectomy was performed. This procedure failed since the patella continued to displace. Subsequently a patellectomy and quadricepsplasty were performed on the right knee. Because of the excellent result, the family insisted on a third operation on the left knee. This was performed on December 22, 1955. The results in both knees were considered excellent, with normal motion, and continued increase in power.

Case 17. J.B., a woman, twenty-two years old, had a history of infrequent transient dislocation of both patellae. On August 18, 1955, the left knee was operated upon. Since the chondromalacia was mild, only a quadricepsplasty was performed. The patient regained normal motion without recurrent dislocation and is anxious to have the right knee operated upon. However, there was gradually increasing asymptomatic crepitus in the knee operated upon. Results in this case have been classified as good.

The experience in the last two cases suggests that in this particular type of repair, patellectomy is an important part of the operation and one should not attempt the quadricepsplasty procedure alone. If one wishes to allow the patella to remain, some other type of plastic procedure should be performed.

Case 10. M. G., a man, forty-one years old, developed recurrent lateral dislocation of the quadriceps apparatus after a fracture of the patella which had been treated by total excision. In July 1953, a quadricepsplasty was performed. In spite of infection and temporary drainage, an excellent result was achieved with restoration of full painless motion and good power without further dislocation.

The significance of this case places emphasis on the fact that patellectomy in itself will not always suffice. The dislocation of the quadriceps tendon may occur without the presence of the patella.

The remaining patients in this series all have complete motion and can undertake all activities. As in all cases of patellectomy, there is a common finding. When the knee is extended or flexed against resistance, there is an area of weakness as the knee passes through the arc of 140 degrees to 160 degrees of motion. This mild weakness is not handicapping, but we believe one should recognize its existence.

## CONCLUSION

The selection of the operation for correction of recurrent dislocation of the patella should depend upon the patient's age. In the adult, the pathological changes in the patellofemoral joint lead to mechanical arthritis unless patellectomy is performed. Our procedure corrects the intra-articular defects. The patients in this series have been followed for a period of one and one-half to twelve years without evidence of recurrence or deterioration of the quadricepsplasty. The excellent function gained suggests that this procedure should have preference in the correction of recurrent dislocation of the patella in adults.

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## DISCUSSION

**Dr. Emil D. W. Hauser, Chicago, Illinois:** I would recommend patellectomy with quadricepsplasty for the older patient in whom there is chondromalacia or advanced arthritis of the knee. For the younger patient, I would prefer a total tendon transplantation. In this connection I would like to emphasize that I have not done a total tendon transplantation in a child under twelve years of age. Recurrent dislocation in children is usually congenital and is associated with genu valgum. In all children, I therefore correct the genu valgum first and by so doing have avoided the need for corrective surgery for recurrent dislocation of the patella in most instances.

I believe that a total tendon transplantation offers an excellent cosmetic result, that the patella protects the knee and acts to give better leverage, and thus more power, to the quadriceps than if it is removed. Furthermore, a transplantation of the attachment of the patellar tendon distally improves the functional capacity of the quadriceps.

My experience with a total tendon transplantation for recurrent dislocation of the patella has been entirely satisfactory. There have been no recurrences.

I believe that the patellectomy and quadricepsplasty as described by Dr. West and Dr. Soto-Hall is a sound operation and is indicated in recurrent dislocation with advanced chondromalacia and arthritis.

**Dr. Ernest M. Burgess, Seattle, Washington:** This excellent paper pointed out the necessity for patellectomy for recurring dislocation of the patella in the adult, regardless of etiology. Dr. West and Dr. Soto-Hall also proposed a means of medial repositioning of the patellar and quadriceps tendons to prevent postoperative lateral tendon subluxation. Their operative technique is, to my knowledge, original and their excellent end results would certainly seem to justify acceptance and use.

I would agree that patellectomy is the proper procedure in these cases if chondromalacia and degenerative changes exist. Patellofemoral arthritis, rather than age, should be the decisive factor. Occasionally, an individual in the second or third decade of life with infrequent subluxation may be operated upon and present no gross articular changes. Under such circumstances medial rerouting of the quadriceps mechanism alone, using one of the several available effective methods, will suffice. We have seen, as have the authors, well marked patellar chondritis with mirror-image changes in the femoral condyles present in children. One of the patients presented today was eleven years old. She responded well to patellectomy on both knees.

In the vast majority of cases of chronic degenerative arthritis in the knee, the earliest demonstrable articular changes appear in the patellofemoral component of the joint. Chronic patellar subluxation, patellofemoral incongruity and instability make up some of the several known causes of this lesion. Patellectomy alters deranged joint mechanics.

Recurrent dislocation of the patella must be regarded as a mechanical problem not alone of the joint, but also of the entire distal quadriceps mechanism. The authors have corrected it by shortening, medially displacing, and resuturing the tendon. This method inevitably delays healing time and knee mobilization compared with simple vertical incision and simple patellectomy with defect closure. We know, however, that the quadriceps mechanism can continue to subluxate laterally and cause symptoms even after patellectomy. Transfer is designed to forestall this complication.

During the past ten years, aside from cases seen on charity and teaching services, I have performed patellectomy seven times on six private adult patients for recurring dislocation. All had extensive chondromalacia. The authors reported twenty cases over a similar period of time. This would indicate the relative infrequent need for this type of surgery in the adult. Either the patient requires surgery at an earlier age or as not infrequently happens, the patella stabilizes spontaneously during adolescence.

**Dr. Soto-Hall (closing):** Dr. Hauser's operation has certain fundamental steps which we think are paralleled by the procedure which we have advocated, that is, the restoration of quadriceps-tendon tension and its medial shift in order to improve the power of the vastus medialis. We have reached the same goal by different paths.

We wish to emphasize again that the operative technique which we have offered is suitable only for adults, and principally for those in whom articular-cartilage changes are present either in the patella or the femoral condyle.

The pathological findings which we have noted can be classified in three groups:

1. True chondromalacia, probably on a vascular basis;
2. Degenerative changes, so-called polished surfaces, which result from improper pressure stresses leading to wearing down of the articular cartilage so that the subchondral bone is exposed;
3. Osteochondral fractures.

Any of these, when moderately advanced, is an indication for patellectomy with quadricepsplasty, especially when opposing surfaces are diseased. We have used this operation also in the simple unstable patella with severe chondromalacia and have been pleased with the results.

Time and experience have convinced us that in properly selected cases this procedure will give a good and lasting result.

# Joint Changes Following Experimental Partial and Total Patellectomy*

BY ANTHONY F. DEPALMA, M.D., AND JOSEPH J. FLYNN, M.D.,
PHILADELPHIA, PENNSYLVANIA

Critical analysis shows that long-term results following total excision of the patella leave much to be desired. It is true that many workers have reported excellent and good results following this procedure. However, analysis of their cases, in most studies, reveals that sufficient time had not elapsed to evaluate adequately the ultimate end results. It is also true that following total excision of the patella, it is possible to develop a quadriceps muscle sufficiently strong to extend the knee completely and to provide the knee joint with the stability necessary for normal function. On the other hand, the quadriceps muscle of the affected limb rarely achieves the power, tone, and volume equal to that of the normal side. The majority of patients in whom patellectomy was done complain of a constant dull ache in the knee joint which is aggravated by long periods of walking or standing; many are aware of a sense of instability, especially on descending steps; and, in all patients, varying degrees of crepitation are felt and heard on flexion and extension of the knee joint. Scott, in 1949, recorded the long-term results of 196 fractures of the patella; of these, 101 were treated by total patellectomy. Analysis of the 101 patellectomies disclosed that only 5 per cent of the patients considered that they had a normally functioning joint; 90 per cent complained of a constant ache, and 60 per cent complained of "giving way" of the knee joint. Todd, in 1950, observed that, when fracture of the patella was treated by total excision of the patella, there was less quadriceps power than when the fracture was treated by suture of the fragments. Bond, in 1952, noted that, following total patellectomy, extension could be restored but aching and discomfort were common complaints. These observations, together with those of many others, fail to support the premise propounded by Brooke and supported by Watson-Jones that the function of the knee joint is enhanced by the absence of the patella which Brooke believed to be in the process of phylogenetic reduction.

Our personal experience with patellectomy forces us to conclude that the patella is an essential component in the functional mechanism of the knee joint. Its loss, although unavoidable in some instances, decreases the over-all functional efficiency of the knee joint. The resulting loss of power, tone, and volume of the quadriceps muscle following this procedure renders the knee joint vulnerable to repeated abnormal stresses and strains incidental to function. It is reasonable to assume that the accumulative results of these noxious factors must be followed by alterations in the soft tissues, and in the cartilaginous and osseous elements of the joint. The investigation reported herein was preceded by a pilot study on thirty adult rabbits; in fifteen a hemipatellectomy was performed, and in fifteen a total patellectomy. Within three to six weeks after the surgery was performed, 62 per cent of the animals in which hemipatellectomy had been done had dislocation of the patella, usually to the lateral side of the knee joint. It became apparent that the subluxation *per se* played the major role in development of the degenerative alterations noted. This preliminary study cast some doubt on the findings recorded by Bruce and Walmsley in 1942 and Cohn in 1944, who reported severe changes in the knee joints of rabbits following partial and total patellectomy. Under normal conditions the extensor apparatus of the rabbit is lax and unstable; the patella can be readily dislocated with only minimal force. On the other hand, the extensor apparatus of the dog is very stable; the patella is firmly supported on the anterior surface of the femur and is dislocated only with great force. For this reason the dog was believed to be the animal of choice for this investigation. Alterations in the intercondylar sulcus and the articular cartilage of the medial condyle of the femur of dogs following patellectomy were recorded by Girardi.

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* Presented as a Scientific Exhibit at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February 1 to 6, 1958 (Received for publication March 4, 1957).

## METHOD OF STUDY

Forty-five adult dogs were used for this investigation; of these seven were discarded for the following reasons: in one animal, the joint became infected as determined by culture; two animals died during the course of the operation from anaesthesia; two animals became ill and died following operation; and in another two the patella subluxated. The animals were divided into three groups. In the first group, a partial patellectomy in the sagittal plane was performed; in this group were thirteen animals and the medial one-half of the patella was removed. In the second group, which comprised seventeen animals, the entire patella was excised. The third group consisted of fifteen animals; in six animals, the superior half of the patella was excised, and in nine animals the inferior half of the patella was excised. In all groups, the operative procedure was carried out through a medial parapatellar incision. A similar incision was made on the opposite knee which was the control joint

All operative procedures were performed with a strict aseptic technique. Any animal with gross evidence of hypertrophic changes in either knee joint was eliminated from this study. At the time that the animal was sacrificed, culture of material from the joint was made; in one animal only did the patellectomized joint demonstrate evidence of gross contamination. This animal was not included in the investigation. As the result of these precautions, thirty-eight animals provided the material for this study. The animals were sacrificed at intervals from twenty-three to 338 days.

Before the animal was sacrificed, a clinical evaluation of the knee joint was made. The presence or absence of swelling, periarticular thickening, limitation of motion, crepitus, sensitivity to palpation, and a limp were determined and recorded. Roentgenographic examinations were made of all knee joints prior to the operation and immediately before the death of the animal. In each instance, gross examination of the fresh knee joints was done immediately after they were obtained from the animal and the observations were recorded. Next, still in the fresh state, the joints were photographed. Finally, the specimens were placed in a 10 per cent solution of formaldehyde and were made ready for microscopic study. Serial sections were made through the patellar bed of each specimen; the sections were studied and the observations were recorded.

## ALTERATIONS OBSERVED FOLLOWING PARTIAL PATELLECTOMY IN THE SAGITTAL PLANE

As previously recorded, the material for this phase of the study was provided by thirteen dogs; two animals were discarded during the course of the study, a total of eleven animals being available for final evaluation. The animals were sacrificed at intervals varying from twenty-three to 261 days. Clinical examination of the animals before removal of the knee joints revealed, in all instances, some swelling and periarticular thickening on the side on which the hemipatellectomy had been performed. These joints were sensitive to palpation; and, when moved passively some restriction of motion was demonstrable on flexion and extension. When the extreme ends of the arcs of motion were attained, the animals gave evidence of pain. In spite of these findings, only two animals in this group limped. The clinical findings were more pronounced in the animals which were sacrificed late in the study. It became apparent that there was a progressive increase in the intensity of the joint changes with increasing age. On the other hand, the opposite joint in which a simple arthrotomy had been performed disclosed no clinical manifestations indicative of joint disease.

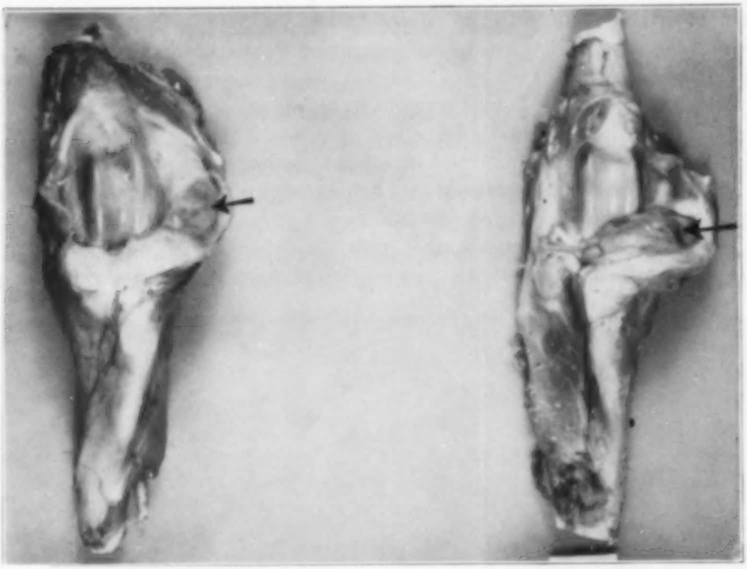


Fig. 1-A

Partial patellectomy (twenty-three days). In the right joint the thickened fibrous tissue is lined by clusters of synovial villi forming a pannus which extends over the medial margin of the remaining portion of the patella; in the left joint no changes are discernible.

In all instances upon opening the patellectomized joint in the fresh state, varying degrees of serosanguineous fluid was found. The fluid was thick and gummy; and, in some of the joints obtained in the late stages of the study, the fluid contained many flakes of fibrin. It was interesting to note that the earliest alteration occurred in the patellar bed. It comprised the formation of fibrous tissue covered by clusters of synovial villi in the

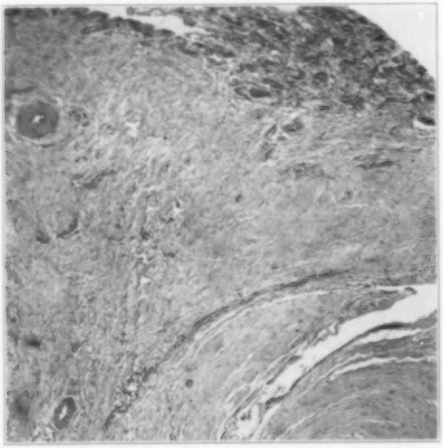


Fig. 1-B

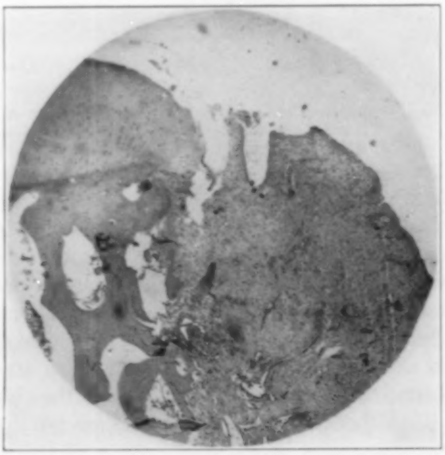


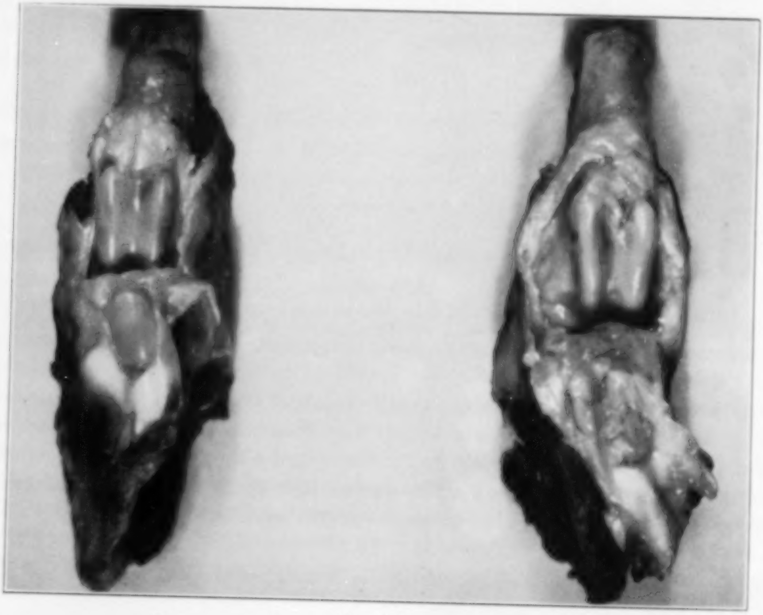
Fig. 2

Fig. 1-B: Partial patellectomy in twenty-three-day specimen shown in Fig. 6 (photomicrograph, × 50). Note the intense hyperplastic connective-tissue response immediately adjacent to the margin of the cut surface of the patella. This tissue is covered by many layers of synovial cells.

Fig. 2: Partial patellectomy in forty-day specimen (photomicrograph, × 33). Soft tissue adjacent to cut surface of the patella has assumed the histological characteristics of fibrocartilage. It is densely packed with fibrocartilage cells and lined by synovial cells.

area immediately surrounding the remaining half of the patella. The hyperplastic tissue extended over both the medial and lateral margins of the patellar fragment like a pannus. This was first observed in a knee joint obtained twenty-three days after operation (Figs. 1-A and 1-B). This specimen showed no changes on the femoral side of the patellofemoral joint, and the control joint exhibited no gross abnormalities.

The changes were more advanced in a joint studied forty days after surgery. An irregular growth of dense fibrous tissue covered the edge of the remaining segment of the patella and larger clusters of synovial villi were encountered than were noted in the twenty-three-day specimen. Grossly, the articular surface of the hemipatella appeared normal. It was interesting to note that the portion of the quadriceps tendon immediately adjacent to the cut edge of the patella was indented and fitted accurately over the corresponding femoral condyle. This tissue was dense, glistening and, grossly, had assumed the characteristics of fibrocartilage (Fig. 2). For the first time, alterations, minimal in intensity, were discernible in the articular cartilage of the lateral femoral condyle as far as the intercondylar groove. However, no response of the subchondral bone in the form of marginal osteophytes was noted at this stage of the investigation. The synovial membrane in the lateral recesses of the joint also appeared normal. Macroscopic and microscopic examination of the opposite joint of the animal disclosed no abnormal findings.



L FIG. 3-A R

Partial patellectomy (188 days). In the right joint there are extensive alterations in the patellar bed, and the articular cartilage of the remaining portion of the patella shows fraying and pitting. Chondro-osteophytes are demonstrable on the intercondylar femoral surface. There are no alterations in the left joint.

Although knee joints examined forty days after surgery showed slight increase in the gradient of involvement, severe alterations were not encountered until approximately five months had elapsed. From that time on, extensive changes were noted in the patellofemoral joint. A joint examined 188 days after surgery demonstrated these alterations (Figs. 3-A, 3-B, and 3-C). The articular surface of the remaining portion of the patella immediately adjacent to the cut surface was frayed, pitted, and fibrillated. The patellar remnant was partially covered by a pannus of fibrous tissue. The lateral half of the patellar bed was obliterated by fibrous tissue and synovial villi. The tissue of the patellar bed had the consistency of tough fibrocartilage. On the anterior surface of the lateral femoral condyle (the femoral side of the patellofemoral joint), marginal osteophytes were observed. Chondro-osseus excrescences were noted also in the intercondylar surface. It became obvious that the articular surfaces of the femur which came in contact with the irregular, rough fibrous tissue in the patellar bed responded in a manner consistent with hypertrophic arthritis.

A knee joint studied 261 days after hemipatellectomy revealed even more advanced changes than those already recorded. Before this animal was sacrificed, clinical examination revealed that the joint was swollen, knobby, and unusually tender to palpation. This animal walked with a pronounced limp. Upon opening the joint, a large quantity of thick, gummy, viscous, brownish synovial fluid was encountered. The remnant of the patella was almost completely covered by fibrous tissue creeping over the articular surface from its periphery; the articular cartilage showed advanced regressive changes (Figs. 4-A and 4-B). It was interesting to note that on either side of the piece of the remaining patella, two large concave areas of tough, fibrocartilaginous tissue with a smooth, glistening articular surface had formed in the lateral expansions of the quadriceps apparatus. These fitted snugly over the corresponding femoral condyles. The anterior articular surface of the femur was pitted and contained several irregular chondro-osteophytes. Along the outer margin of the lateral femoral condyle, large irregular peripheral chondro-osteophytes were discernible (Fig. 4-C). Also, the inner aspect of the medial condyle exhibited fraying and pitting of its articular cartilage.

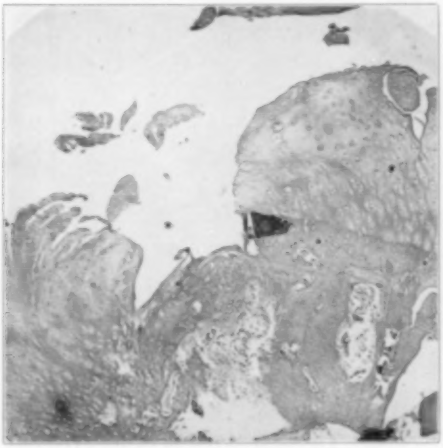


FIG. 3-B

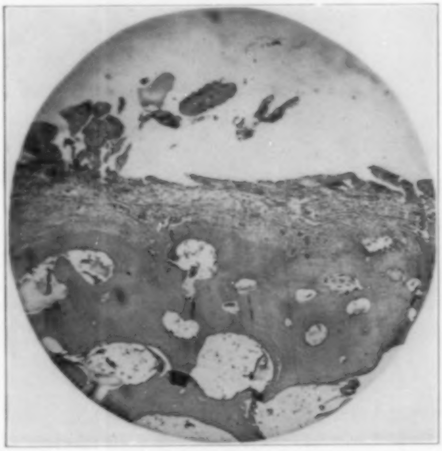


FIG. 3-C

Fig. 3-B: Partial patellectomy in 188-day specimen (photomicrograph, × 50). The articular cartilage adjacent to the cut surface of the patella is fibrillated and shredded, indicative of advanced degeneration.

Fig. 3-C: Partial patellectomy (photomicrograph, × 33). Anterior surface of the femur of the specimen shown in Figs. 3-A and 3-B. The cartilage on the anterior surface of the femur exhibits advanced degeneration.

The most extensive alterations were encountered in the knee joint of an animal sacrificed 280 days after hemipatellectomy (Fig. 5). The remnant of the patella was incorporated in an irregular mass of new tissue with the consistency of bone. The articular surface of the patella was completely devoid of cartilage. It was interesting to observe that the quadriceps apparatus had shifted laterally so that most of the articular surface of the bony patellar bed articulated with the lateral femoral condyle. On the lateral femoral condyle there were large, irregular, marginal excrescences which increased greatly the width of the anterior surface of the femur. Large, tough fibrous adhesions completely

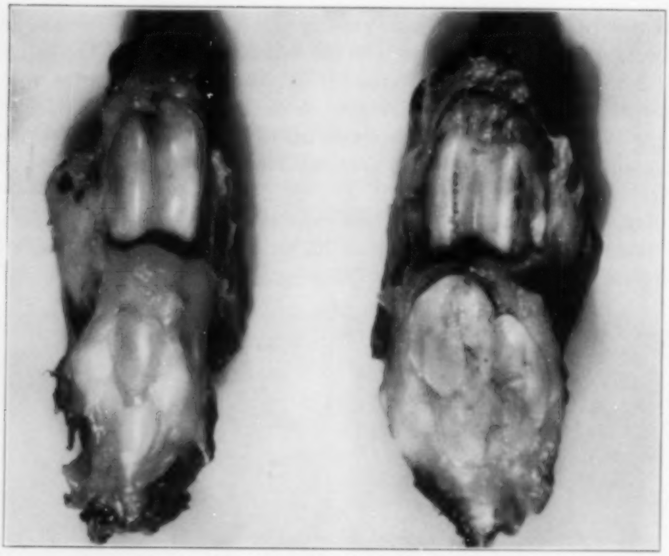


FIG. 4-A

Partial patellectomy (261 days). In the right joint, the patellar bed, including most of the patella, is covered by dense irregular fibrous tissue. The femoral condyles reveal erosions and pitting of the articular cartilage; peripheral osteophytes are demonstrable on the outer margin of the lateral femoral condyles. In the left joint there are no changes.

covered the articular surface of the anterior aspect of the femur. The medial half of the lateral femoral condyle was devoid of articular cartilage. The medial recess of the synovial cavity was obliterated by a pannus of fibrous tissue which projected over and blended with the outer aspect of the medial femoral condyle.

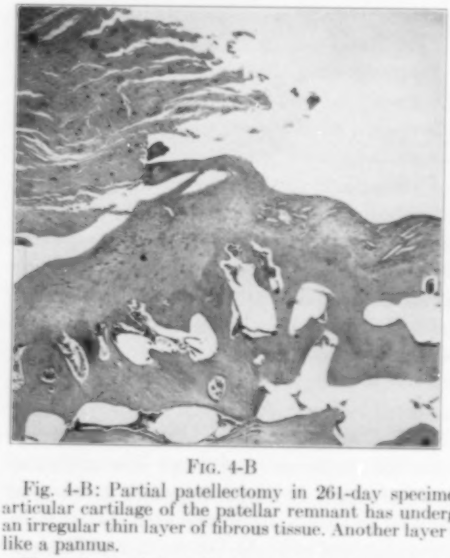


FIG. 4-B

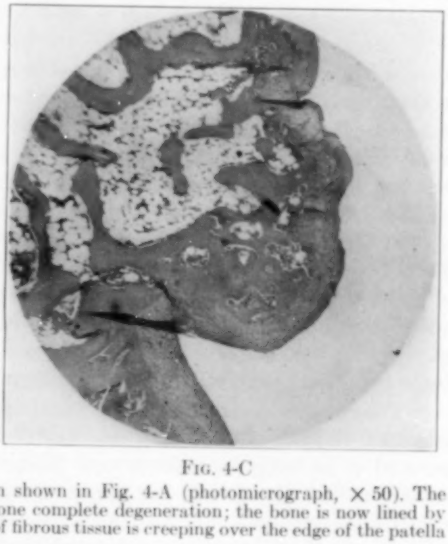


FIG. 4-C

Fig. 4-B: Partial patellectomy in 261-day specimen shown in Fig. 4-A (photomicrograph, × 50). The articular cartilage of the patellar remnant has undergone complete degeneration; the bone is now lined by an irregular thin layer of fibrous tissue. Another layer of fibrous tissue is creeping over the edge of the patella like a pannus.

Fig. 4-C: Partial patellectomy (photomicrograph, × 33). Anterior articular surface of femur of specimen in Figs. 4-A and 4-B. A large chondro-osteophyte has formed on the outer margin of the lateral femoral condyle.

### *Analysis of Observations*

Analysis of the observations noted in the group of animals in which a hemipatellectomy was performed reveals that any disturbance in the normal mechanism of the knee joint is conducive to the production of regressive changes in the soft tissues and in the cartilaginous and osseous components of the articulation. These alterations are progressive in nature and ultimately result in advanced disintegration of the joint and dysfunction. The changes affect primarily the elements comprising the patellofemoral joint. On the patellar side of the joint, marked fibrous-tissue proliferation occurs which is transformed to fibrocartilage. In this area, a pronounced response is also noted in the synovial membrane in the form of tabs and villous formations. On the femoral side of the patellofemoral joint, the essential abnormalities are obliteration of the suprapatellar pouch by tough fibrous adhesions, the formation of irregular, sharp marginal chondro-osteophytes and erosion, pitting, and fragmentation of the articular cartilage.

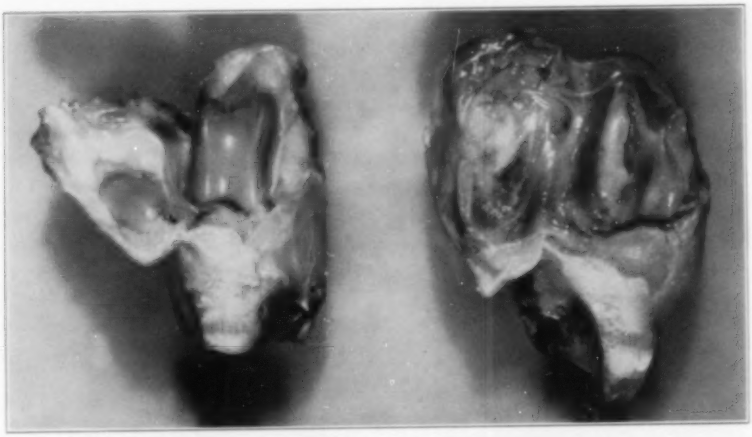


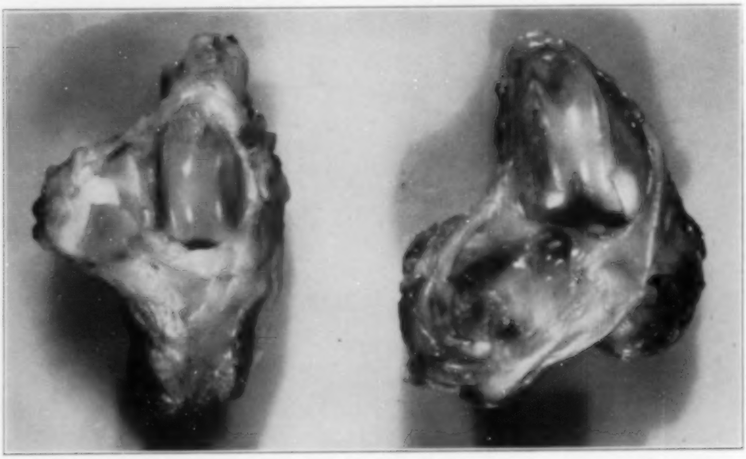
FIG. 5

Partial patellectomy (280 days). In the left knee there are large irregular marginal excrescences on the lateral femoral condyle which increase the width of the anterior surface of the femur. The remaining portion of the patella has been incorporated in an irregular mass of fibrous tissue and tissue with a cartilaginous and bony consistency. The medial recess of the synovial cavity has been obliterated by a pannus of fibrous tissue. The right joint shows no alterations.

## OBSERVATIONS NOTED FOLLOWING TOTAL EXCISION OF THE PATELLA

Seventeen animals provided the material for this phase of the study. Three of the animals had to be discarded, leaving a total of fourteen animals for final study. They were sacrificed at intervals from fifty-six to 338 days after the patellectomy was performed. As in the first group, clinical examination of the dogs before they were sacrificed revealed that the patellectomized joint, in all instances, was swollen and had periarticular thickening. Those examined in the late stages of the study exhibited a knobby configuration. Invariably, the joints were painful on palpation and several animals limped. Some restriction of the arcs of flexion and extension was demonstrable when the joints were moved passively. These findings were more pronounced in the joints examined in the late stages of the investigation. The opposite joints revealed no abnormalities. Examination of the opened, fresh patellectomized joint, in all instances, revealed the presence of varying amounts of yellowish and, in some instances, brownish, thick, viscous, synovial fluid which occasionally contained rice bodies.

The earliest alterations recorded in this investigation were encountered in the knee joint removed fifty-six days after surgery. Passive flexion and extension produced considerable crepitation in the joint. Upon opening the joint, a yellowish, viscous fluid escaped; however, the quantity of the fluid was not sufficient to distend the joint cavity. The entire synovial membrane was discolored golden-yellow and was hyperplastic (Fig. 6-A). The patellar bed was covered by numerous long pedunculated and branching synovial villi. Some villi contained hemorrhagic blebs. It appeared that the blebs were the result of trapping of the larger villi between the femoral condyles and the tibia resulting in hemorrhage into the villi. The patellar bed was rough, irregular, and ill defined. Although the patellar bed had a firm consistency, there was no gross evidence of cartilaginous or osseous tissue formation (Figs. 6-A, 6-B, and 6-C).



R FIG. 6-A L

Total excision of the patella (fifty-six days). In the left joint the patellar bed is irregular; it shows a severe hyperplastic response with the formation of numerous hemorrhagic synovial villi. The right joint shows no alterations.

The anterior surface of the femur showed the most marked alterations in the articular cartilage. Here, the cartilage was thinned, eroded in spots, and frayed. At the periphery, the cartilage was covered by a pannus of synovial membrane. In addition, the medial femoral ridge was discolored and its cartilage was frayed and pitted.

A joint examined seventy-two days after the patella was removed showed severe involvement of all its component parts. The capsule was thick and oedematous and the entire synovial lining was stained a light brown color. It appeared that the synovial membrane was impregnated with broken-down blood pigments (Fig. 7). The entire patellar bed was involved in a hyperplastic process comprising outgrowths of fibrous tissue and large, grapelike clusters of branching and bulbous synovial villi. No cartilaginous or osseous formations were demonstrable grossly in the patellar bed. Both femoral condyles showed thinning and pitting of their outer articular margins; the medial condyle was broader than the lateral and its articular cartilage exhibited advanced degeneration. The anterior surface of the femur was covered by a pannus of thickened synovial tissue which extended downward and laterally into the lateral recesses of the synovial cavity.

The next two joints to be described are of special interest since they showed changes of minimal intensity in the patellar bed and in the condylar regions. These specimens lead one to conclude that in some instances, the patellar bed is converted into a smooth, gliding organ producing no deleterious effects on the femoral side of the joint. However, as will be shown by the severity of the changes in other joints, this may very well be a

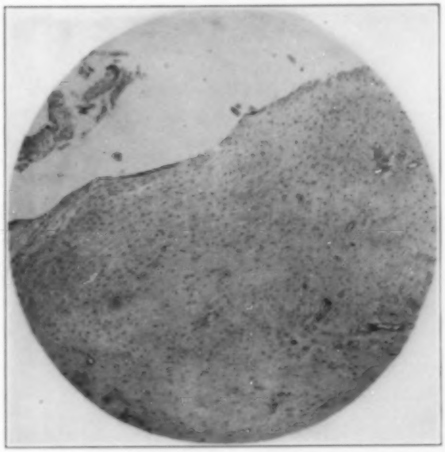


FIG. 6-B

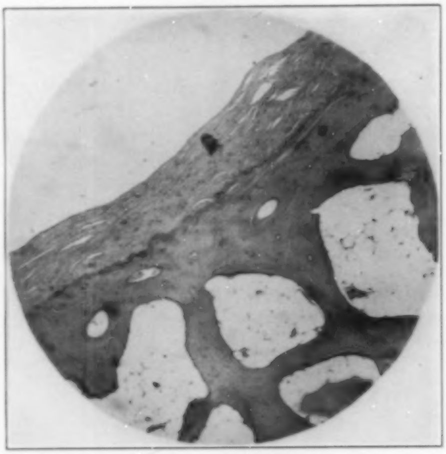


FIG. 6-C

Fig. 6-B: Total excision of the patella (photomicrograph, × 66). The patellar bed of same fifty-six-day specimen as that in Fig. 6-A. The patellar bed has been obliterated by dense growing connective tissue whose histological features are those of fibrocartilage; it is lined by layers of compressed synovial cells and synovial villi.

Fig. 6-C: Total excision of the patella (photomicrograph, × 66). The anterior articular surface of the femur of specimen shown in Fig. 6-A. The articular cartilage is thinned and shredded; it has lost the pattern of normal hyaline cartilage.

temporary state only. With continuous function, this acceptable and efficient apparatus eventually breaks down and is replaced by a patellar bed with a rough, irregularly scored surface in which fragments of fibrocartilage are demonstrable. Concomitant alterations are also noted in the femoral condyles and on the anterior articular surface of the femur.

FIG. 7

Total excision of the patella (seventy-two days). In the right joint the entire patellar bed exhibits marked overgrowth of fibrous tissue and grapelike clusters of synovial villi. The articular cartilage of the femoral condyles is thin and pitted. The left joint exhibits no alterations.

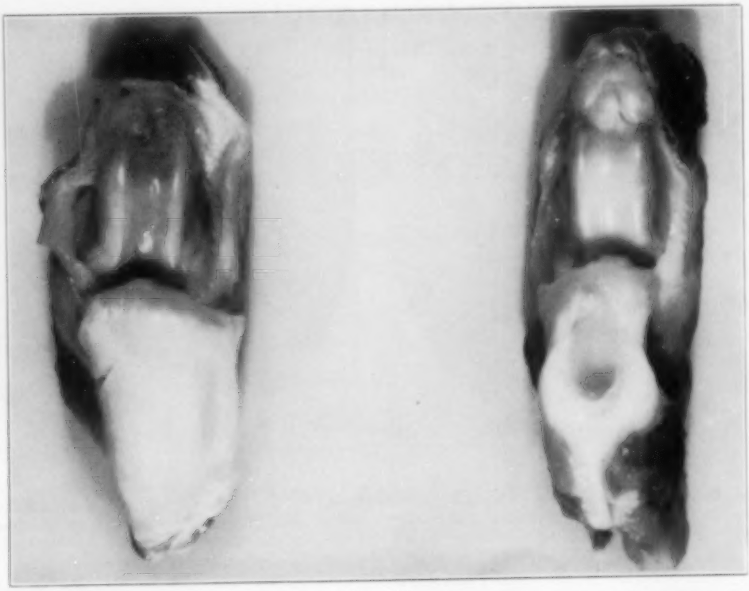


FIG. 8-A

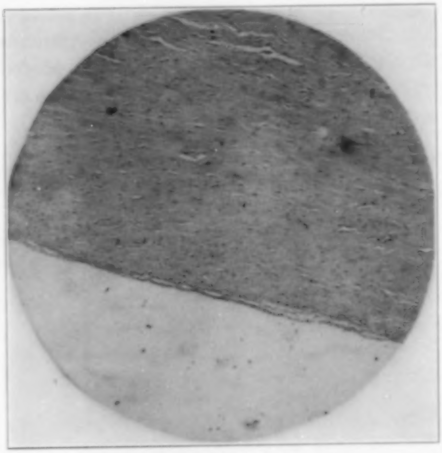


FIG. 8-B

Fig. 8-A: Total excision of the patella (117 days). In the left joint, the patellar bed is smooth and glistening and no changes are demonstrable in the femoral side of the joint. In the right joint, no changes are discernible.

Fig. 8-B: Total excision of the patella (photomicrograph, × 66). The patellar bed of the specimen depicted in Fig. 8-A is composed of dense cellular fibrocartilage with a smooth surface lined by a compressed layer of synovial cells.

Figure 8-A depicts the alterations in a knee joint 117 days after total patellectomy. The patellar bed of tough fibrous tissue with a smooth articular surface was lined by a thin layer of glistening synovial membrane (Fig. 8-B). No scoring of the surface, no villous formation, and no metaplasia to fibrocartilage or bone were noted. Grossly, the anterior surface of the femur and the femoral condyles appeared to be normal.

A joint studied 181 days after patellectomy revealed some scoring and vertical striations of what, undoubtedly, was once a smooth, even, glistening patellar bed (Fig. 9). Although the femoral side showed only minimal alterations, the thinning and pitting of the articular cartilage of the femoral condyles and the irregularity of their peripheries were evidence that regressive changes were in progress and these with time and usage would ultimately terminate in widespread hypertrophic changes. The progressive nature of these processes was emphasized in a joint examined 214 days after excision of the patella (Fig. 10). The patellar bed contained numerous vertical ridges of fibrous tissue. Scattered throughout the portion of the quadriceps apparatus were several nodules of cartilaginous and osseous consistency. Clusters of synovial villi were demonstrable on the surface and especially at the periphery of the patellar bed. The femoral condyles were beginning to press out grooves in the patellar area. On the anterior surface of the femur,

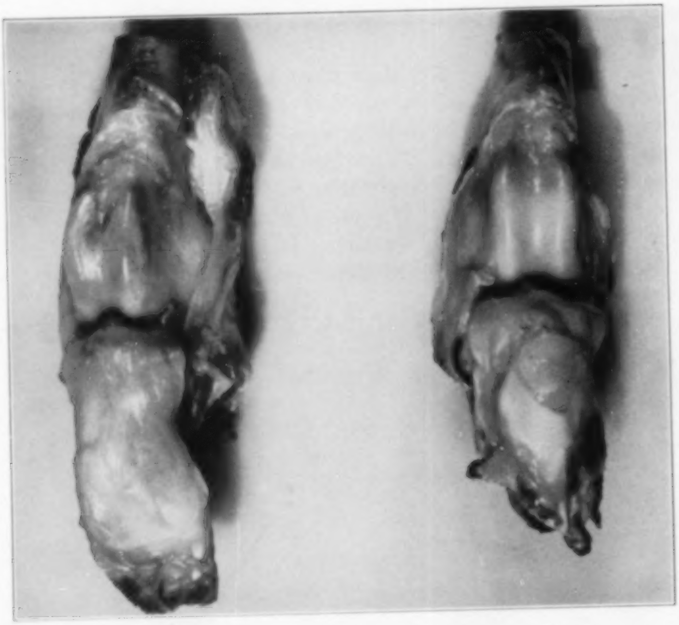


FIG. 9

Total excision of the patella (181 days). In the left joint, there are scoring in the patellar bed, minimal alterations with thinning and pitting of the articular cartilage of the femoral condyles. In the right joint there are no alterations.

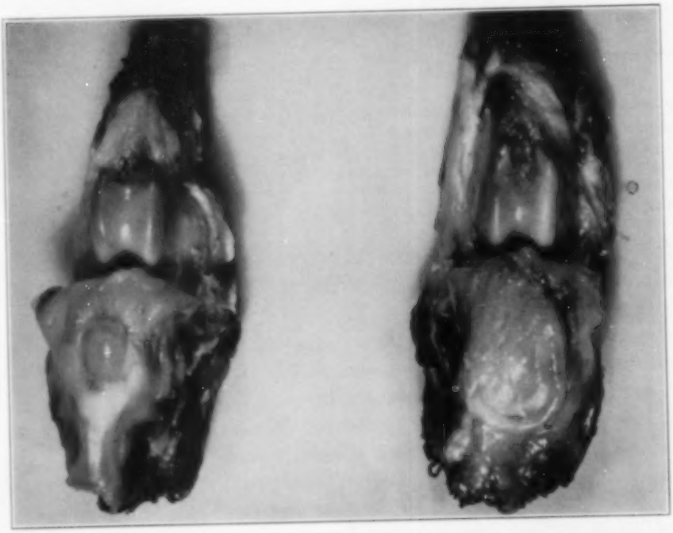


FIG. 10

Total excision of the patella (214 days). In the right joint, there are roughening of the patellar bed and several firm nodules of the consistency of bone and cartilage. The articular cartilage on the anterior surface of the femur is thin and frayed. Note the hyperplastic synovial response in this region. In the left joint, no changes are evident.

the cartilage was thin, frayed, and discolored. The synovial membrane in this region showed hyperplastic changes.

Another animal sacrificed 338 days after total patellectomy revealed even more pronounced changes than those just recorded (Fig. 11-A). In this instance, the patellar bed exhibited an advanced hyperplastic process. It was thickened, rough, and contained numerous vertical ridges. Although the surface was glistening, it was studded by synovial villi and tabs of varying sizes and shapes (Fig. 11-B). It contained large areas of cartilaginous and bony consistency. Severe alterations were discernible in the condylar regions. The lateral condyle was worn away completely and the intercondylar area on the anterior surface of the patella was studded and almost completely obliterated by irregular osteophytes and a pannus of fibrous tissue which projected distally over the entire lateral femoral condyle (Fig. 11-C). The lateral recess of the synovial cavity was also obliterated by fibrous tissue.

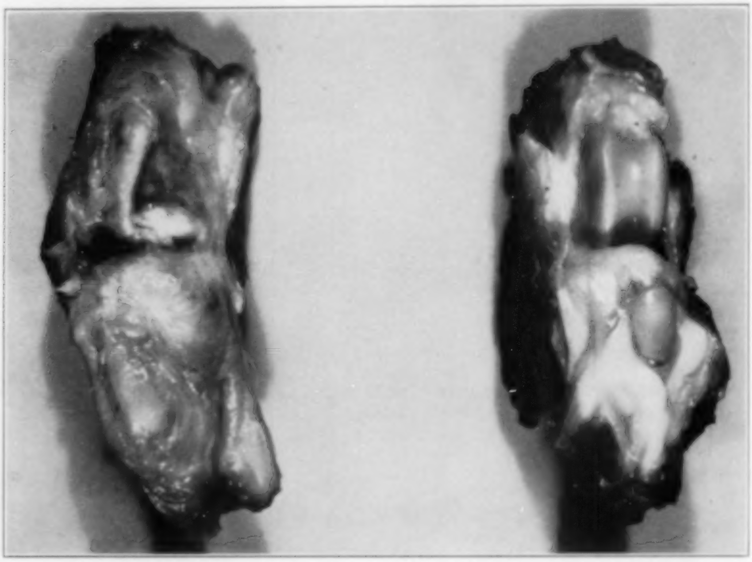


FIG. 11-A

Total excision of the patella (338 days). The right joint exhibits extensive hyperplastic alterations in the patellar bed which is studded with tough fibrous and synovial ridges and tabs. Areas of bony consistency in the bed are discernible. The femoral side of the joint exhibits advanced degenerative alterations with complete destruction of the lateral femoral condyle; the lateral synovial recesses have been obliterated by dense fibrous tissue. The left joint is normal.

In this late stage of the investigation, irregular areas of cartilaginous and bony consistency in the patellar tendons were constant findings. This feature was clearly demonstrated in a specimen examined 214 days after complete excision of the patella (Fig. 12). The joint had extensive hyperplasia in the patellar bed, and three large pieces of tissue resembling bone and cartilage were seen within its substance.

In general, all specimens obtained after 214 days disclosed the same severe abnormalities. These comprised pronounced thickening and striation of the patellar bed and the formation of fibrocartilage, cartilage, and bone in the extensor apparatus. Also, there was a proliferative response of the synovial membrane of the entire joint cavity. The femoral condyles invariably showed advanced hypertrophic alterations including marginal osteophytes, erosion of articular cartilage and obliteration of the intercondylar area on the anterior surface of the femur by bony and cartilaginous excrescences.

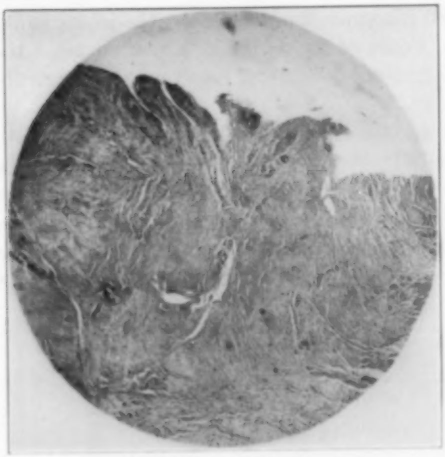


FIG. 11-B

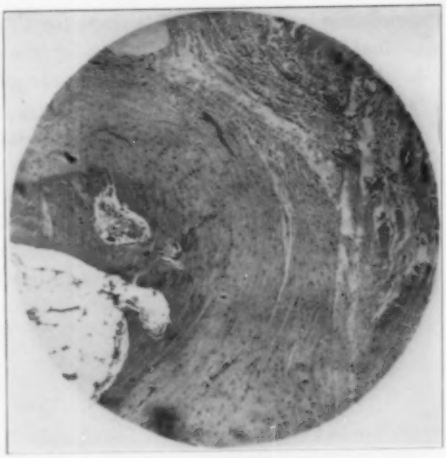


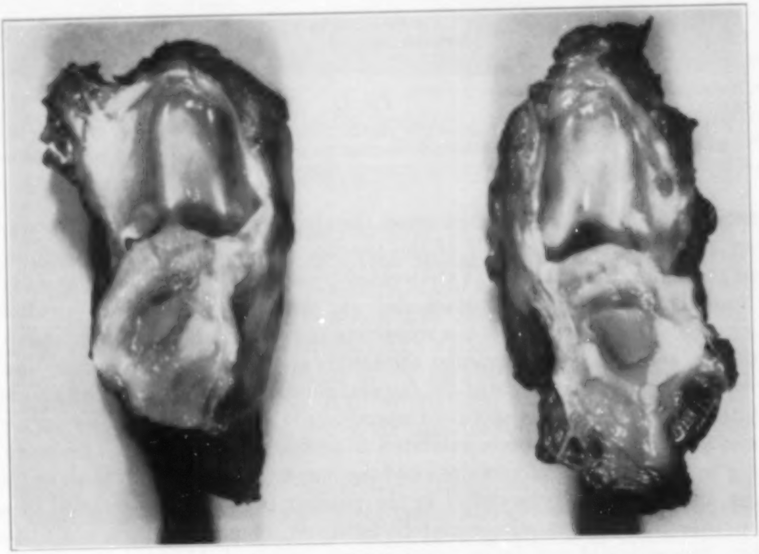
FIG. 11-C

Fig. 11-B: Total excision of the patella (photomicrograph, × 33). Patellar bed of specimen depicted in Fig. 11-A exhibits irregular vertical ridges of dense fibrocartilaginous tissue lined by large branching synovial villi.

Fig. 11-C: Total excision of the patella (photomicrograph, × 66). Femoral articular surface of specimen depicted in Fig. 11-A. The articular hyaline cartilage of the lateral condyle has been replaced by dense connective tissue lined by layers of synovial cells. Note the active osteoblastic process in the subchondral bone leading to the formation of a peripheral osteophyte.

### EXCISION OF SUPERIOR OR INFERIOR HALF OF THE PATELLA

In this group there were fifteen animals; the superior pole of one knee joint, usually the right joint, was excised in six animals and the inferior pole in nine animals. In two animals the patella subluxated; they were discarded, thirteen being available for final evaluation. In general, the animals had little or no disability from the time following the operation to the date of sacrifice. Only two animals limped. In these the patella had

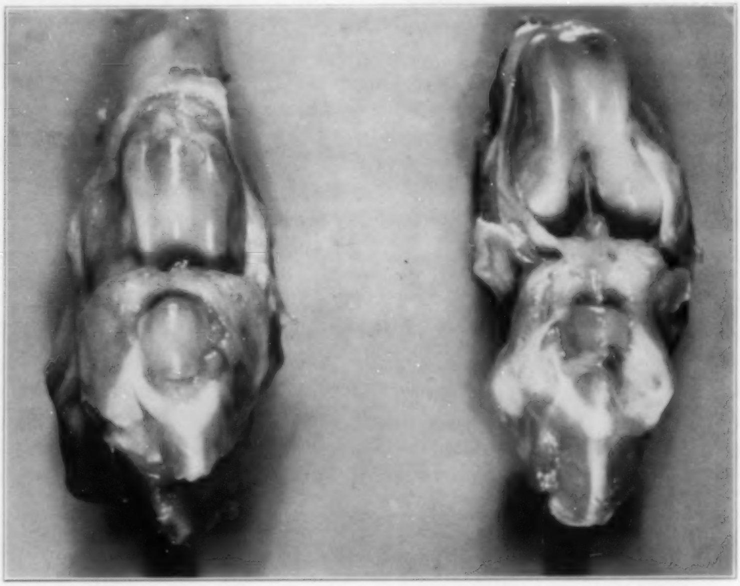


R FIG. 12 L

Total excision of the patella (214 days). In the right joint observe the formation of bonelike nodules in the patellar bed. In the left joint there are no alterations.

dislocated laterally. In all, except for the two aforementioned animals, the joints had a normal range of active and passive motion. Some of the animals, sacrificed after the fourth month, demonstrated some mild periarticular swelling and crepitus in the partially patellectomized joint.

Inspection of the joints in animals sacrificed after the third month and up to the fifth month revealed alterations in the articular surface of the extensor apparatus and in the articular cartilaginous surface of the patella and femoral condyles. These alterations never equaled those noted in the animals in which a hemipatellectomy had been done in the sagittal plane or in which a total patellectomy had been performed. However, the animals sacrificed in the sixth and seventh months exhibited severe alterations. In no instance was there complete disintegration of the articulation.


R FIG. 13 L

Excision of the superior pole of the patella (thirty-four days). In the left joint the defect in the patellar bed has been obliterated by fibrous tissue. The synovial response is minimal. The right joint is normal in every respect.

Specimen 96 (Fig. 13) is an example of the changes observed thirty-four days following resection of the superior half of the patella. The bed previously occupied by the resected portion of the patella was obliterated by dense fibrous tissue, the outer layer of which functioned as a gliding surface and was covered with synovial membrane. The articular cartilaginous surfaces of the remaining portions of the patella exhibited no gross alterations. There was no periarticular thickening and the synovial response was minimal in degree. The articular surfaces of the femoral condyles demonstrated no alterations.

In the joints of animals sacrificed approximately two months after surgery all the components of the articulations exhibited a pronounced response. The areas affected primarily were the parapatellar regions and the non-articular lateral regions of the femoral condyles. In all instances the defect in the patellar bed made by removal of a portion of the patella was obliterated completely by dense, rough, and furrowed fibrous tissue (Fig. 14). The synovial membrane in all regions exhibited thickening and formations of clusters of villi particularly over the anterior surface of the distal end of the femur and over the infrapatellar fat pad (Fig. 15). Along the lateral aspects of both femoral condyles small firm fibrous excrescences were found. All of these observations are clearly demonstrable in Specimen 03 (Fig. 16).

It appears that the findings noted were the result of the increased functional activity to which these joints were subjected for the first thirty days following surgery. In all instances, after the first month the animals used their knees freely without any attempt to protect them. With continued normal function these alterations begin to recede and the joints tended to assume a more normal state. This observation is supported by the findings noted in the animals sacrificed three, four, five, six, and seven months after partial patellectomy. Specimen 86 (Fig. 17) and Specimen 560 (Fig. 18) were obtained eighty-three days and 124 days, respectively, following patellectomy; in the former the superior pole was excised and in the latter, the inferior pole. In each instance, the defect in the patellar bed was obliterated by fibrous tissue which was covered with synovial membrane. The tissues surrounding the patella were slightly thickened and irregular but the surfaces were smooth and glistening. Only a minimal synovial reaction was demonstrable; the articular cartilage of the femoral condyles of both specimens was macroscopically and microscopically essentially normal (Fig. 19).

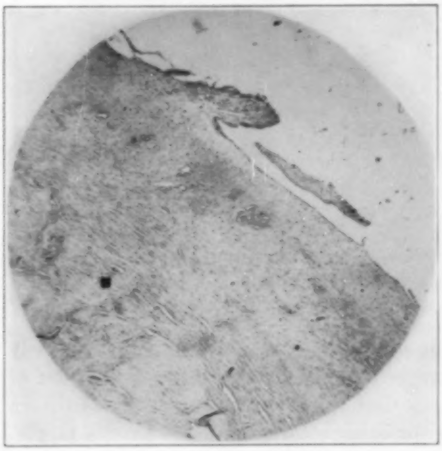


FIG. 14

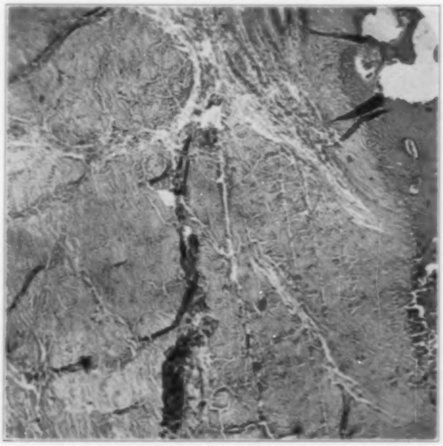


FIG. 15

Fig. 14: Excision of the superior pole of the patella (photomicrograph, × 33). The patellar bed of a sixty-four-day specimen has been obliterated by dense, cellular tissue resembling fibrocartilage.

Fig. 15: Excision of the inferior pole of the patella (photomicrograph, × 50). Parapatellar area of a seventy-two-day specimen shows marked thickening of the connective tissue and profound synovial response.

Specimen 91 (Fig. 20) and Specimen 87 (Fig. 21) were obtained 162 days and 153 days, respectively, following patellectomy. The alterations in Specimen 91 were slightly greater in intensity than those noted in Specimens 86 and 560 (Figs. 17 and 18) and the changes in Specimen 87 were even more severe. The tissues around the remaining portion of the patella were thickened and rough, having a fibrocartilaginous consistency. In spite of these alterations the articular surfaces of the patella and the femoral condyles were practically normal. Formation of flat osteocartilaginous excrescences was noted on the lateral aspect of the femoral condyles and on the anterior surface of the femur immediately proximal to the condyles.

It becomes apparent that after the initial surgical trauma the joints go through a period of re-adjustment in order to meet the functional demands in their altered state. During this period the joint components exhibit varying degrees of tissue responses such as were noted in the joints of animals sacrificed approximately sixty days after patellectomy. Following this period the tissues tend to stabilize and tend even to return to a

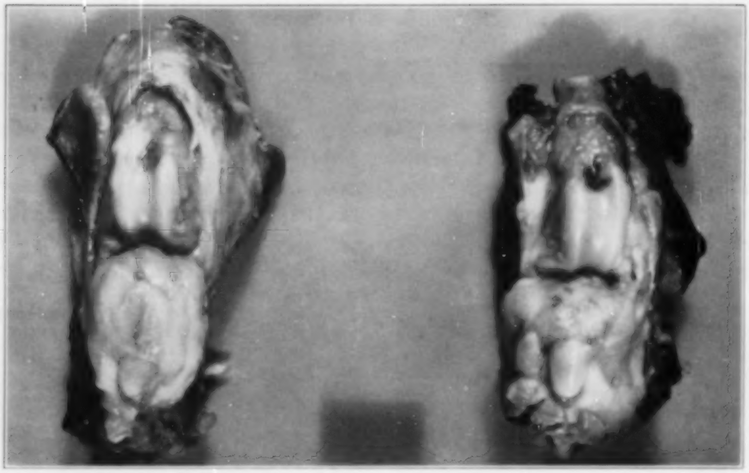


FIG. 16

Excision of the inferior pole of the patella. The right joint of a seventy-two-day specimen reveals a severe hyperplastic response of the synovial membrane and formation of firm excrescences on the lateral margin of the femoral condyle. The remaining portion of the patella is surrounded by dense thickened and furrowed fibrous tissue. The opposite joint reveals no abnormalities.

normal state. This trend was observed in the joints of animals sacrificed approximately ninety, 120, and 150 days following patellectomy. After the sixth month, alterations of minor intensity again appear, making it obvious that the alterations in the quadriceps apparatus associated with resection of the inferior or superior pole of the patella predis-

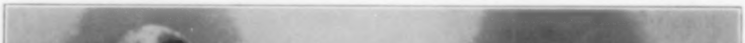


FIG. 17

Excision of the superior pole of the patella. In the right joint of an eighty-three-day specimen, the intense tissue response noted in Fig. 16 has subsided. The defect in the patellar bed has been obliterated by fibrous tissue, but its surface is smooth and glistening. The left joint is normal.

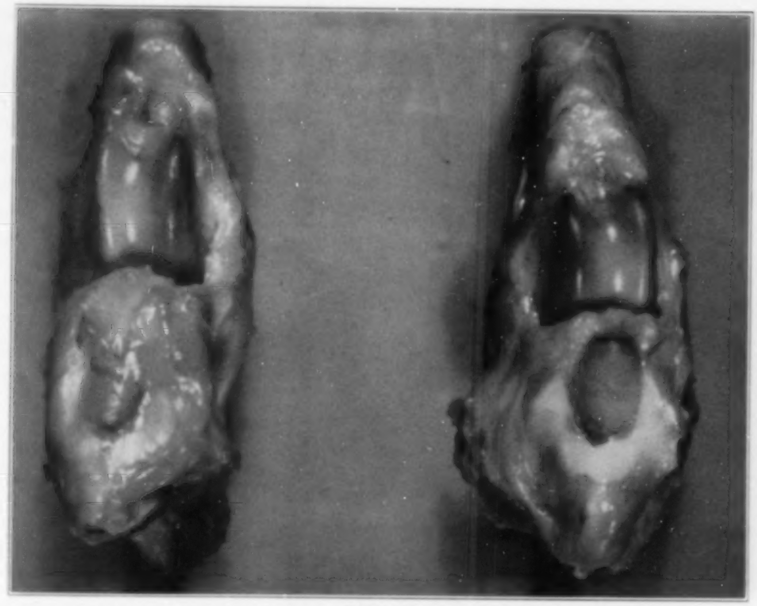


FIG. 18

Fig. 18: Excision of the inferior pole of the patella. The findings in this 124-day specimen are similar to those noted in Fig. 17.

Fig. 19: Excision of the inferior pole of the patella (photomicrograph, × 33). In the parapatellar area of a 124-day specimen, the hyperplastic process observed in Fig. 18 is less intense; the articular cartilage of the patella appears normal.

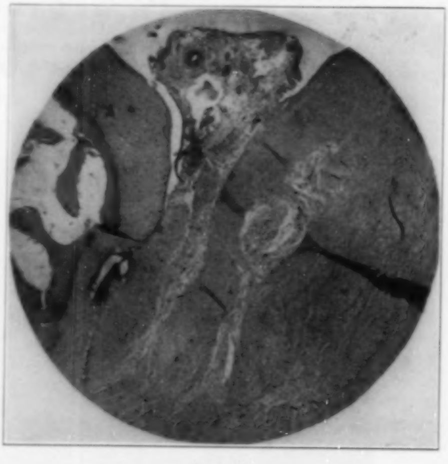


FIG. 19

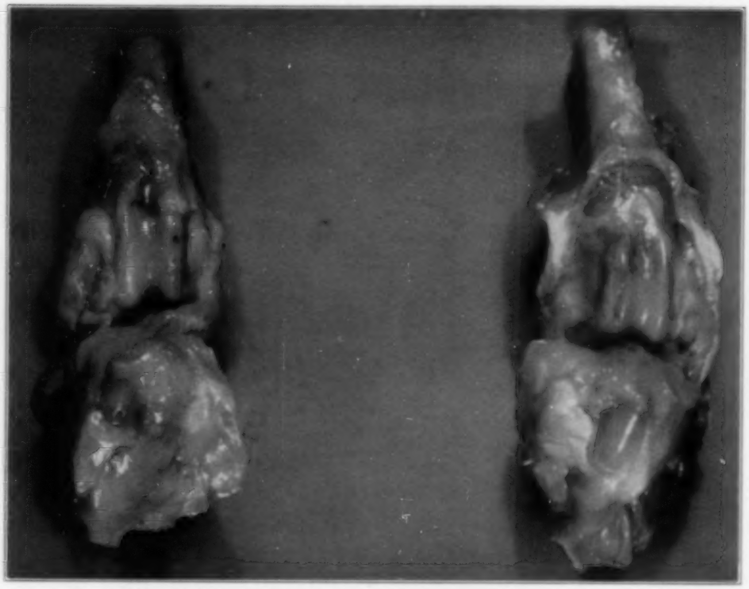
poses the knee joint to the slow development of degenerative alterations which are progressive in nature. It must be assumed that although these joints function normally for a long time, eventually clinical evidence of degenerative alterations will be manifested.

## DISCUSSION

This investigation provides unequivocal evidence that:

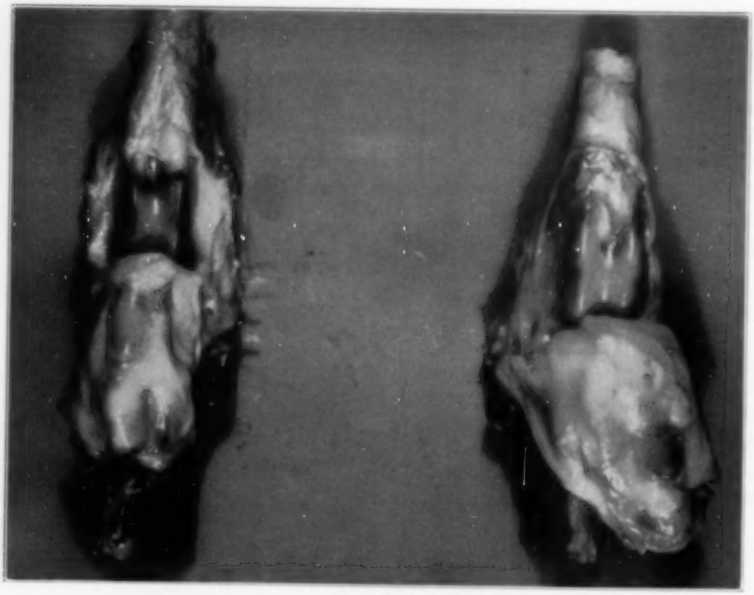
1. Total and partial patellectomy in the sagittal plane in dogs results in pronounced progressive degenerative alterations in the knee joints.

2. Excision of the superior or inferior halves also produces abnormal alterations, but these changes are by far less extensive than those encountered following total excision of the patella. However, even in this latter group the changes are progressive but mildly so; hence, it is reasonable to assume that if the animal lives long enough the alterations may reach sufficient magnitude to produce varying degrees of dysfunction. It is reasonable to assume that similar alterations in the configuration of the knee joints of other animals, including man, may be followed by changes similar to those observed in the dog. However, in view of the difference in the anatomical construction of the knee joint of the dog and that of man it is difficult to assess the intensity of such changes.



R FIG. 20 L

Excision of the superior pole of the patella. In the right joint of this 162-day specimen the patella is surrounded by dense fibrous tissue in which firm nodules are palpable. Excrescences are noted on the lateral aspects of the femoral condyles and on the anterior surface of the femur. The articular cartilage of the patella appears macroscopically normal. In the left joint in this instance, there is some erosion of the upper portion of the medial femoral condyle.



R FIG. 21 L

Excision of the inferior pole of the patella. In the left joint of this 153-day specimen, the changes are similar to those encountered in the specimen shown in Fig. 20.

One must admit that other factors may play a role in the production of the alterations described herein. Although culture of material from all joints was done at the time of sacrifice, still the possibility of infection cannot be completely ruled out. Repeated aspiration of the joint might throw more light on this aspect of the problem. On the basis of this study, one is justified in making the plea that the patella in man be not indiscriminately removed and that other methods be sought and designed to supplant this injudicious and prevalent practice. Whenever possible the superior or inferior pole of the patella should be spared since by so doing the normal mechanism of the knee joint is not severely impaired.

## CONCLUSIONS

1. Excision of part or the whole patella in the dog results in progressive abnormalities consistent with advanced hypertrophic arthritis; the alterations are least in magnitude when the superior or inferior half of the patella is spared.
2. When these alterations are severe, pain and dysfunction result.
3. The regions of the joint most severely affected are those comprising the patellofemoral joint.
4. It is reasonable to assume that the changes are the result of abnormal friction of soft tissues against cartilage and bone and impairment of the mechanism whereby the articular cartilage on the anterior surface of the femur is adequately nourished.
5. It is reasonable to assume that similar alterations in the configuration of the knee joints of other animals, including man, may be followed by similar changes. However, the differences in anatomical construction of the knee joint of the dog and that of man preclude accurate assessment of the severity of such alterations.
6. Whenever possible, the patella or at least its superior or inferior pole should be preserved, and that in those instances in which deletion appears mandatory, new methods should be designed whereby the normal mechanics of the joint are restored.

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# The Presence of Crystals in the Cytoplasm of Large Cells Adjacent to Sites of Bone Absorption*

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Present knowledge of the origin and function of the osteoclast is still mainly based on speculation because of the technical difficulties in the examination of the living cell. There is no doubt that the osteoclast is present in sites where bone is being remodeled; this is the basis for the opinion that the osteoclast is causally related to the process. In recent reviews both McLean and Hancox are prepared to assume that the cells do play some part in bone absorption but what the part is, is not known. McLean repeats his previous contention that the osteoclasts do not phagocytose the bone. Urist and McLean concluded that histiocytes phagocytosed calcified bone matrix. On the basis of decalcified material Jordan thought that osteoclasts at least phagocytosed decalcified bone matrix. McLean has never seen mineral débris within osteoclasts when they are in the immediate vicinity of bone undergoing absorption, although he noted that his technique only allows the demonstration of aggregated bone salt. The observations to be presented here are not limited by the resolving power of the light microscope, and it is our opinion that it must now be considered possible that, during bone resorption, mineral does pass through these cells in the form of bone crystals.

## MATERIALS AND METHODS

The bone studied was from the lateral subperiosteal aspect of the distal metaphysis of the femur just proximal to the distal epiphyseal line. It was obtained from newborn infants. The superficial connective tissue was stripped from the bone, the periosteum being left in position. A slice of bone and periosteum less than 0.5 millimeter in thickness and about 0.5 centimeter square was then removed. The subsequent methods used in the preparation of the tissue for electron microscopy have been reported previously [5].

The tissue was somewhat difficult to section, as the cells studied usually lay in their lacunae in the undecalcified bone and were covered by a layer of fairly dense periosteal connective tissue. Hence, it was almost impossible to obtain very thin sections of this material. The sections were usually thick, rather knife marked, and fragmented. The illustrations are electron micrographs of the best areas available in the sections obtained. Larger areas were built up from several electron micrographs, pictures of which would not have been suitable for publication. Postmortem degeneration before embedding was taken into account in interpreting the pictures. One rarely obtains human material quickly enough after death to prevent all degenerative changes in the internal structure of cells before fixation. Nevertheless, the results of the first few observations are clear-cut and apparently throw new light on the activities of cells which the authors believe to have been osteoclasts.

## OBSERVATIONS AND DISCUSSION

### *Cell Cytoplasm*

Cell cytoplasm is vacuolated (Figs. 1, 2, and 3), consistent with the foamy or vacuo-

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lated appearance of the cytoplasm of osteoclasts observed through the light microscope. The vacuoles do not appear to be distributed in any particular fashion and are not the large ones which Hancox described in degenerating cells or the large vacuoles seen in osteoblasts in regions of very rapidly forming bone. The multiple small vacuoles might have been caused by postmortem degeneration, but they have not been seen in such profusion in near-by osteoblasts (Fig. 2).

Figure 2 shows the difference between an osteoblast and a cell having cytoplasm which appeared like that in the cells in Figures 1 and 3. Figure 2 is from an area of new-bone formation just proximal to the distal femoral epiphysis near the center of the epiphysis. The larger cell with the vacuolated cytoplasm was the only one found in this particular area with this appearance. The difference in the cytoplasm of this cell and the adjacent osteoblasts was quite obvious. This particular cell did not lie right next to bone.

The most striking feature in the portions of the cytoplasm of the osteoclasts seen in

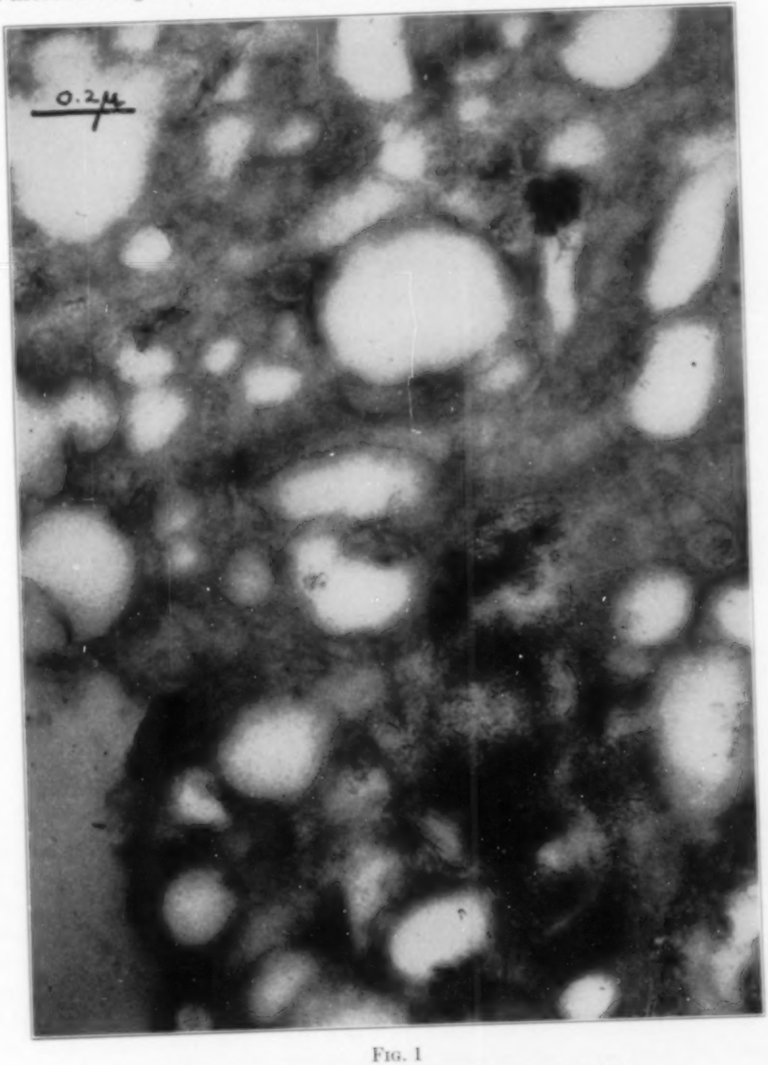

FIG. 1

Aggregates of crystals in the cell cytoplasm (× 80,000).

Figures 1 and 3 is the presence of aggregates of crystals. These crystal collections were only one micron in size or much smaller and were composed of crystals which resembled inorganic bone crystals in size, shape, and density. No electron-diffraction studies have been carried out on them so that their identity is not completely certain but such crystals have not been seen or described in any other cells. The proximity of these cells to the bone undergoing resorption, and the identical appearance between the crystals in them and those in bone matrix strongly suggest that they are crystals of bone salt. The smallest groups appear to be in the cytoplasm between the vacuoles, but the vacuoles may also be

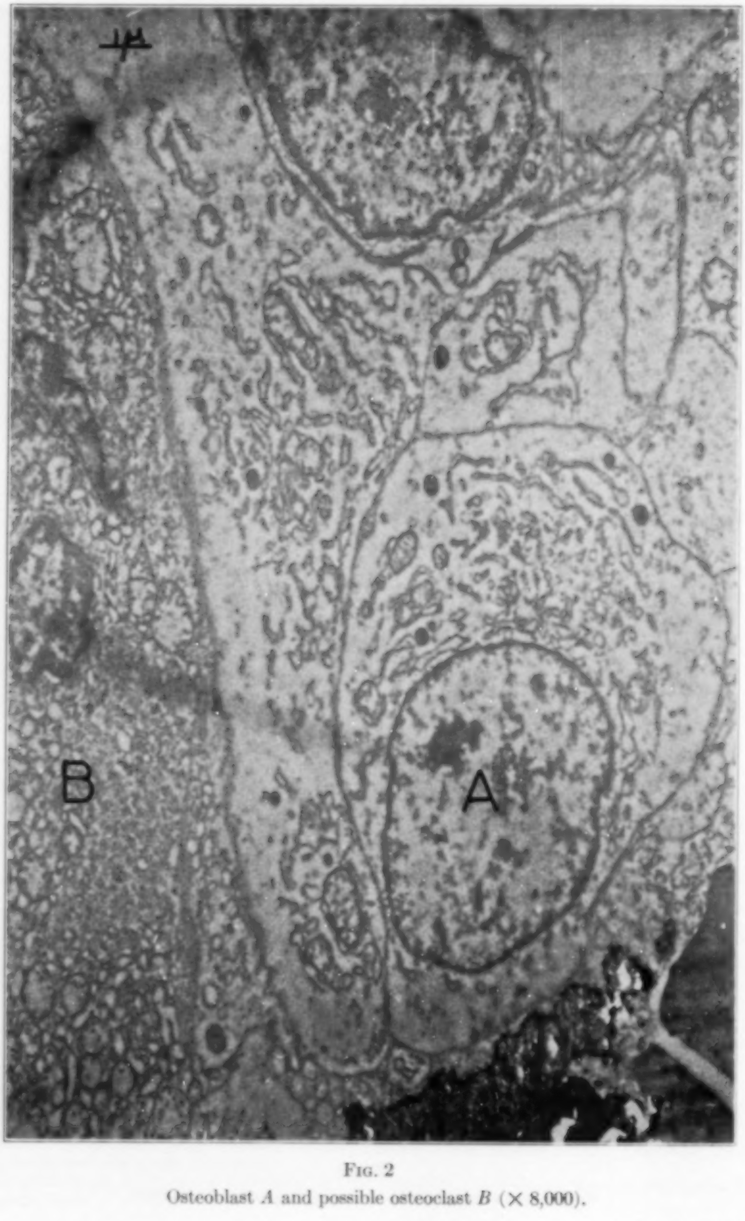

Fig. 2

Osteoblast *A* and possible osteoclast *B* (× 8,000).

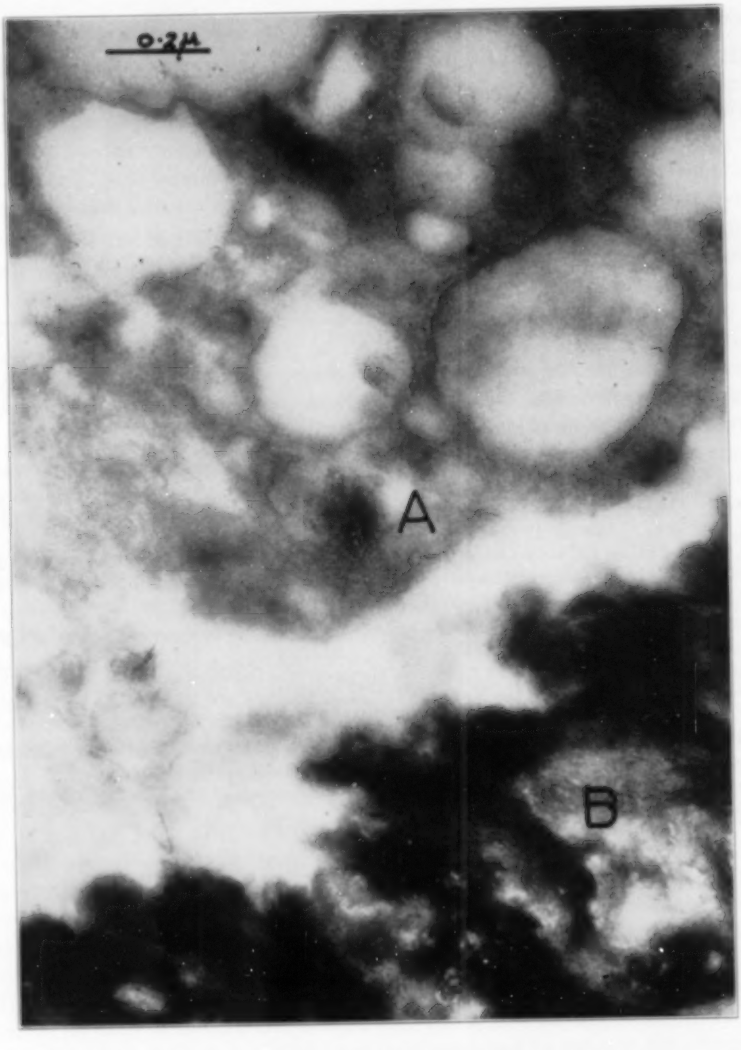

Fig. 3

Cytoplasm of cell *A* containing crystals in close proximity to the calcified bone matrix *B* (× 80,000).

lined with them. The appearance of the larger aggregations suggests that they are both within and outside the vacuoles. No orientation of the crystals in any particular direction was observed. Their presence within the cells is unlikely to be an artefact resulting from crystals being carried there on the knife edge as they have not been noted in osteoblasts. On the other hand, although phagocytosis appears likely, the means by which the crystals reached this position is not certain. One must consider the possibility that the bone salt might have been dissolved from the bone, and during the postmortem period recrystallized in these vacuolated cells. Such a selective site for recrystallization seems unlikely to the authors since other cells of osteoblastic type in the same area did not contain such crystal inclusions.

### *Location of the Cell*

Except where they have been torn away during preparation, the vacuolated cells containing crystals are very close to the bone (Fig. 3), within 0.1 micron at times. In between there is some amorphous material which has not been resolved sufficiently so that one may be sure whether it is part of the cell surface or a very narrow zone of decalcified bone matrix. This zone of amorphous material is so narrow that it could certainly not be seen with the light microscope. It appears that both crystals and organic osteoid matrix are removed almost simultaneously. No good evidence of a "brush border" is offered by these electron micrographs. However a "brush border" is not consistently found in light microscope studies [7] of the osteoclast-bone matrix contact area.

## CONCLUSION

The size, location, and characteristics of these vacuolated cells lead us to believe that they are osteoclasts and that they contain mineral in crystalline form which they have removed from the neighboring bone.

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# The Three-Dimensional Anatomy of Haversian Systems*†

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The structure and development of Haversian systems have taken on new significance since the dangers of retention of radioactive isotopes in bone have become universally apparent. During work with $Ca^{45}$ in bone[5], it was found that the classical studies of Haversian systems, occupied as they were with the fundamental morphology of osseous tissue, or its developmental changes, or its relationship to mineral metabolism, or its mechanical properties[11, 12], did not provide an adequate background of knowledge to explain the pattern of deposition of bone-seeking radioactive isotopes. Therefore, the present study of the three-dimensional anatomy of Haversian systems was begun to help provide that background. In the process, it was realized that the data obtained were not only of toxicological application but were fundamental to the understanding, on a microscopic level, of the mechanical properties and the development of compact bone.

Haversian systems, although they constitute the basic units of most of the compact bone of man and other large vertebrates, are not the only units of organization at the low-power microscopic level. The circumferential lamellae, periosteal and endosteal, and the interstitial lamellae also comprise sizeable fractions of the total substance of compact bone.

This paper is only incidentally concerned with the circumferential lamellae, although, in some ways, they constitute the more fundamental pattern of bone: developmentally, they occur earlier, they represent a primary bone deposit rather than a replacement, and in some smaller animals, for example the rat, mouse, and guinea pig, they comprise the major part of compact bone, since only a few rudimentary Haversian systems develop in these animals. Interstitial lamellae have been widely accepted as residua of Haversian systems. This study, while primarily concerned with Haversian systems, has devoted some attention to interstitial lamellae and has evolved a new explanation which is at some variance with previous concepts of their development.

Haversian systems or osteons course primarily longitudinally in the long bones, and anastomose extensively with one another; they consist of irregularly cylindrical structures composed of concentric lamellae of bone substance and osteocytes ringed around a central canal. They vary in cross-sectional shape from circular to oval. Amprino and Bairati[2] studied cross sections of human and animal long bones and showed that, with age, there was a gradual increase in the area of the compacta occupied by osteons, the greatest increment occurring between the ages of six and fifteen. Godina made a comparable study on dogs and showed the same phenomena occurring on a different time scale, while he also demonstrated minor changes attributable to race and body build. Amprino[1] showed further that comparable parts of the right and the left femur of human beings demonstrated definite differences in their patterns of Haversian systems. Amprino and Bairati's study was the most thorough analysis of single sections from many human beings of different ages, and they concluded that an elaborate process of resorption of compacta with replacement by Haversian systems was operative throughout adult life. They showed, further, that this also occurred extensively in childhood, during which period appositional formation of circumferential lamellae was superimposed to increase the cross-sectional diameter of the compacta. These two processes, therefore, are the major factors in remodeling of

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cortical bone. Amprino and Bairati described the changes in shape, size, and regularity of osteons in single cross sections, noting that, with age, the cross-sectional area of each osteon tended to decrease, that their shape became more regular, and that the total area of interstitial lamellae tended to increase. They also noted larger cross-sectional areas for individual Haversian systems near the endosteum and greater irregularity of contour in the larger osteons. We may conclude, from this evidence, that developmental factors are of vastly greater importance in the evolution of the intimate structure than mechanical forces, since the microscopic pattern is so diverse and fluid in the absence of notable changes in mechanics. However, until three-dimensional reconstructions were attempted, it was evident that the understanding of the structure and spatial relationships of Haversian systems was incomplete.

The technical difficulties attending three-dimensional reconstructions are the reason that so few examples of this type of investigation are available. To give some estimate of these difficulties, one may compare the material of Amprino and Bairati with that of Koltze. The former, which is the most extensive collection described, was derived from 100 postmortem examinations, while the latter was a five-millimeter section of one phalanx; yet, the amounts of raw data obtained in the two studies are quite comparable. Another three-dimensional reconstruction of several single osteons was performed by Filogamo [6, 7]. Since the work of Koltze and Filogamo is relevant to the present study, it will be discussed in more detail later. To complete the list of three-dimensional studies available, the reconstructions of Amprino of the ossified tendons of the chick [1] and the reconstruction of Blechschmidt of the fibula of an embryo are also mentioned.

## MATERIALS AND METHODS

The investigation to be described, a three-dimensional reconstruction of Haversian systems of compact bone, is based on material from the mid-femoral cortex of adult dogs, since it was desired that the anatomical study be made of the same bone from the same animal species as was used for studies of deposition of radioactive isotopes [10]. This laboratory animal was chosen for study because its mineral metabolism seems to be more closely comparable with that of human beings than that of most other laboratory animals.

The dogs used were adult mongrels of unknown age. To verify that all were adults, the distal region of each femur was sectioned longitudinally and no epiphyseal cartilage plate could be found on microscopic section. The dogs weighed between nine and twelve kilograms and were of medium build. Four dogs in all were used, the right femur being the source of material in two, while both femora were used from the other two dogs. One centimeter of the mid-diaphysis of these femora was fixed in formalin, decalcified in 5 per cent nitric acid, and embedded in celloidin. Before embedding, an axial scratch was made on each block to serve as a marker and the proximal part of the blocks was colored with indelible ink. These markers, in conjunction with the linea aspera and the over-all configuration of the bone, permitted precise orientation after mounting. Between 300 and 420 serial sections of each block were made, varying between twenty-five and forty micra in thickness. Each series was composed of sections of uniform thickness. The sections of the first two specimens were mounted unstained directly from the microtome to prevent sections from being mounted upside down. The subsequent blocks were mounted similarly, twelve to a slide, but then a thin application of ether and alcohol was applied momentarily and the celloidin of the twelve sections of each slide was amalgamated as a sheet, which then could be removed from the slide and stained with hematoxylin and eosin. In the first two blocks, the use of the phase microscope was necessary because of the absence of staining. In the subsequent four series, this was unnecessary.

While the separate series were examined through most of their extent, it was soon evident that reconstruction of the entire segment in any one case would be impractical, besides being so detailed that the complexity would obscure any pattern which prevailed. Therefore, it was decided to reproduce a representative portion of several Haversian systems in one area of one of the bones. The findings thus demonstrated were later confirmed for many areas of each of the several series.

Reconstruction was done by an adaptation of the wax-plate method of Born. With the use of the phase microscope, photomicrographs were made of each section, including in each photomicrograph the scratch as a reference marker. When necessary, photomicrographs of several overlapping microscopic fields were made so that composites could be assembled which would relate the reference marker to any portion of the section. All of the photomicrographs were made at a magnification of 104 and no significant optical distortion was noted in the composites which would prevent unambiguous comparison of successive sections.

On the first slide of the series to be reconstructed (Fig. 1), eight representative Haversian systems were selected in the region of the reference marker. These were selected on the twelfth section rather than the first,

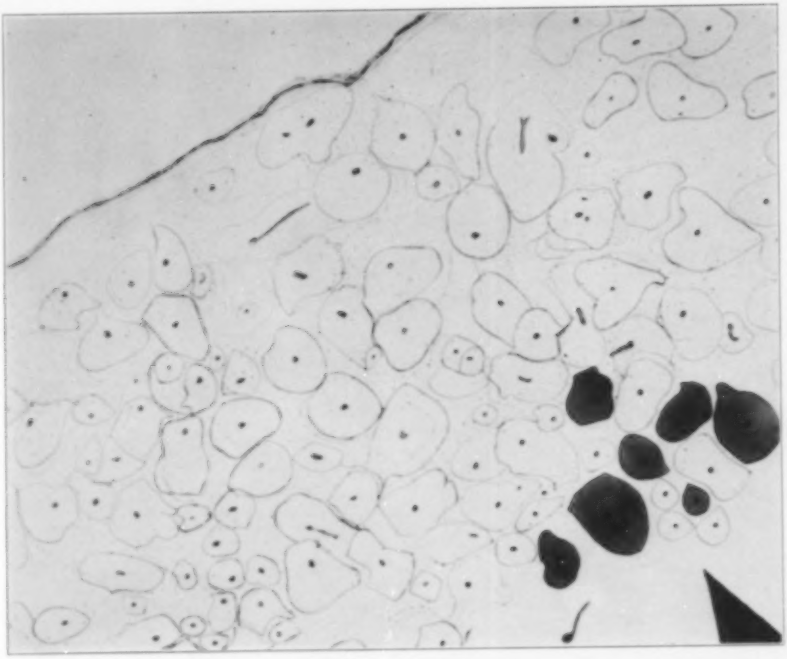

FIG. 1

Drawing of part of Section 1 of modeled segment showing seven of the Haversian systems selected for tracing. The eighth osteon is represented in this section by a vessel in the subperiosteal circumferential lamella with which it is continuous. The axial scratch (lower right) indicates the orientation.

so that they could be traced proximally, as well as distally, for a slight distance. In so doing, it was found that one of these systems was a continuation of a vascular canal coursing longitudinally in the periosteal circumferential lamellae of the first section. The eight systems and their anastomotic descendants were subsequently identified in all successive sections and were photographed. As the eight systems migrated away from the marker, it became necessary to make composite photographs of two to six microscopic fields in order to relate these systems to the reference marker (Figs. 2 and 3).

From these photomicrographs, a blueprint was drawn up showing all of the Haversian systems, cross connections, and anastomoses existing in the region of study. The blueprint, in essence, showed the vascular pattern of this network of Haversian systems. Endosteal and periosteal vascular connections and Volkmann canals were accurately indicated. A model (Fig. 4) was then constructed to show the network in three dimensions, as contrasted with the two-dimensional blueprint. This was done as follows: (1) from each photomicrograph, a sheet of cardboard was prepared showing the precise location of each Haversian canal under study, and the location of the reference marker; (2) every twenty-fourth section was represented by a sheet of transparent plastic; and (3) holes were made in the sheets at the points representing each Haversian canal or vessel. The sheets were then assembled serially on a special frame which held them in the exact relationship indicated by the marker. Individual uninsulated wires were placed through the corresponding holes in the successive sheets. The sheets of cardboard were then cut out and removed from the model. The wires thus represented individual canals and vessels, and the accuracy of their spatial relationships was assured by retention of the plastic sheets. A code was then devised to indicate several of the features of the model. It was decided that those canals which were cloaked with concentric lamellae (Haversian systems) would be represented by insulated wire, while canals in the bone without such investment would be represented by uninsulated wire. Different colors of insulation were assigned and applied to the Haversian systems entering the network at various levels, that is, the original eight systems from Section 1 to Section 48 were colored red, as were all of their branches in this portion of the model. Those systems which entered the model from Section 49 to Section 96 were assigned a yellow color, Sections 97 to 168, blue, Sections 169 to 240, green, and thereafter, black. The bifurcation of a system was colored the same as the proximal segment, and the common system resulting from the anastomosis of two systems of different colors was chosen to be represented by the color of the original system in continuity. The color code, therefore, is entirely artificial and serves merely to facilitate identification of the various systems, since the network otherwise would be overcomplicated. During

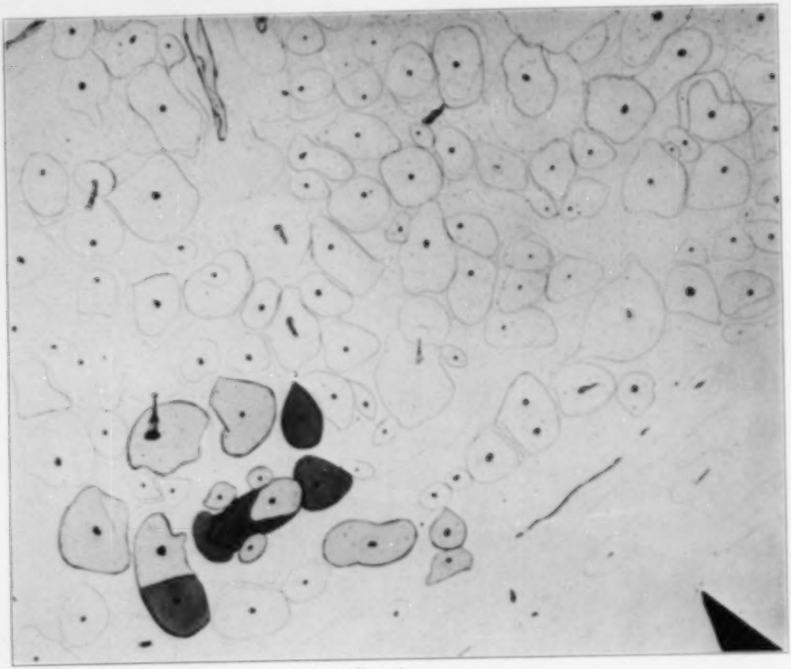

FIG. 2

The middle section of the modeled segment. Note the migration of osteons from the marker toward endosteum and to the left. The greater number of systems shaded shows the extent of bifurcation of systems.

the reconstruction, when a system was found to enter the network under study, it was traced back for a variable extent to determine whether the entering system, followed retrograde, would run in the same general direction as that taken by systems followed distally. In no case was this orientation other than that of the network.

Additional items in the code were as follows. The reference marker was represented by a gray uninsulated wire. Periosteal vascular connections were represented by segments of uninsulated wire shaped like pinwheels, and endosteal vascular connections by corkscrew configurations. Blindly ending systems were noted by a cone of uninsulated wire over the lowest portion of the insulation of the system in question. Volkmann canals were indicated by uninsulated wires running transversely and attached at their extremities to the involved systems by perforation of the insulation.

Since the insulation was of the same thickness throughout, the wire model indicated only the pattern of vessels and systems without reference to the external configuration of the latter. Another model (Figs. 5 and 6) was necessary in order to depict the external shape of the osteons. For this purpose, a few representative systems (the ones colored red from Sections 192 to 240) were selected for reconstruction. Cut-outs were made of the photomicrographs of these sections and each of these was traced on balsa wood of a thickness proportional to the magnification of the photomicrographs and the thickness of the sections. The balsa wood cut-outs were then assembled and glued together in proper orientation to the reference marker. The resulting models, representing about 1.5 millimeters of the axial extent of the systems involved, were about 15.2 centimeters in height. In order to construct models which were more suitable for demonstration, each of the balsa wood replicas was further magnified fourfold by shadowing the photomicrographic cut-outs on an enlarger, tracing the shadow on paper, and constructing styrofoam replicas of the tracings. The styrofoam replicas were four times the thickness of the balsa wood cut-outs and were assembled by means of long wood screws. The balsa model and the styrofoam model were then colored in the same manner as the same systems of the wire model.

Since the major concern of this study was the spatial orientation and the extent of Haversian systems it was necessary to ensure that the models did not represent isolated observations from small fragments of bone. Confirmation of the results with those to be described were obtained by serial examination of many parts of the series modeled and also by numerous examinations of the other series studied.

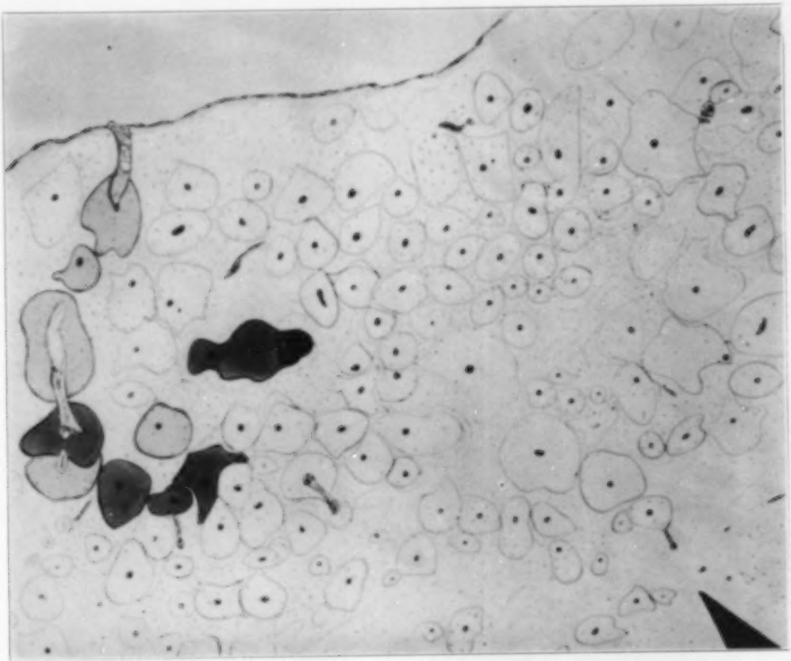

FIG. 3

The last section of the modeled segment, one centimeter from the first. The shaded systems are now close to endosteum and one may be seen communicating by a large bone channel with the marrow cavity. The migration of systems further to the left is obvious.

## RESULTS

### *Spatial Relationships of Osteons*

Through variable numbers of branchings, all osteons except those in the area adjacent to the linea aspera could be traced distally from the regions beneath the periosteal circumferential lamellae to the endosteum. Exceptions to this were a few systems which were found to deviate slightly from this orientation to anastomose with neighboring systems and a few others which ended blindly; but the course of the network from periosteum to endosteum, progressing distally, was not substantially affected by either of these groups.

In approximately one centimeter of the length of the femur, an osteon and its descendants coursed from periosteal lamellae to endosteum. This was most easily demonstrable in areas in which no endosteal circumferential lamellae were present. Where endosteal circumferential lamellae were present, the Haversian systems were found to be continuous with vessels coursing in those lamellae, most of which soon pierced the subendosteal lamellae to anastomose with the marrow circulation, but a few proceeded axially for variable distances in a manner similar to those in subperiosteal circumferential lamellae. Since the total course of most of these vessels involved only a few sections until they reached the endosteum, they did not substantially lengthen the intra-osseous vascular network. The vessels in the subperiosteal lamellae, however, coursed through many serial sections before anastomosing with the periosteal circulation.

The intimate packing of Haversian systems seen on cross sections precluded simultaneous visualization of this pattern for all Haversian systems. The selection of a few systems for modeling thus demonstrated a course of osteons from periosteum to endosteum, superimposed on the predominantly longitudinal orientation.

Besides its course toward the marrow cavity, the network also followed a gentle spiral

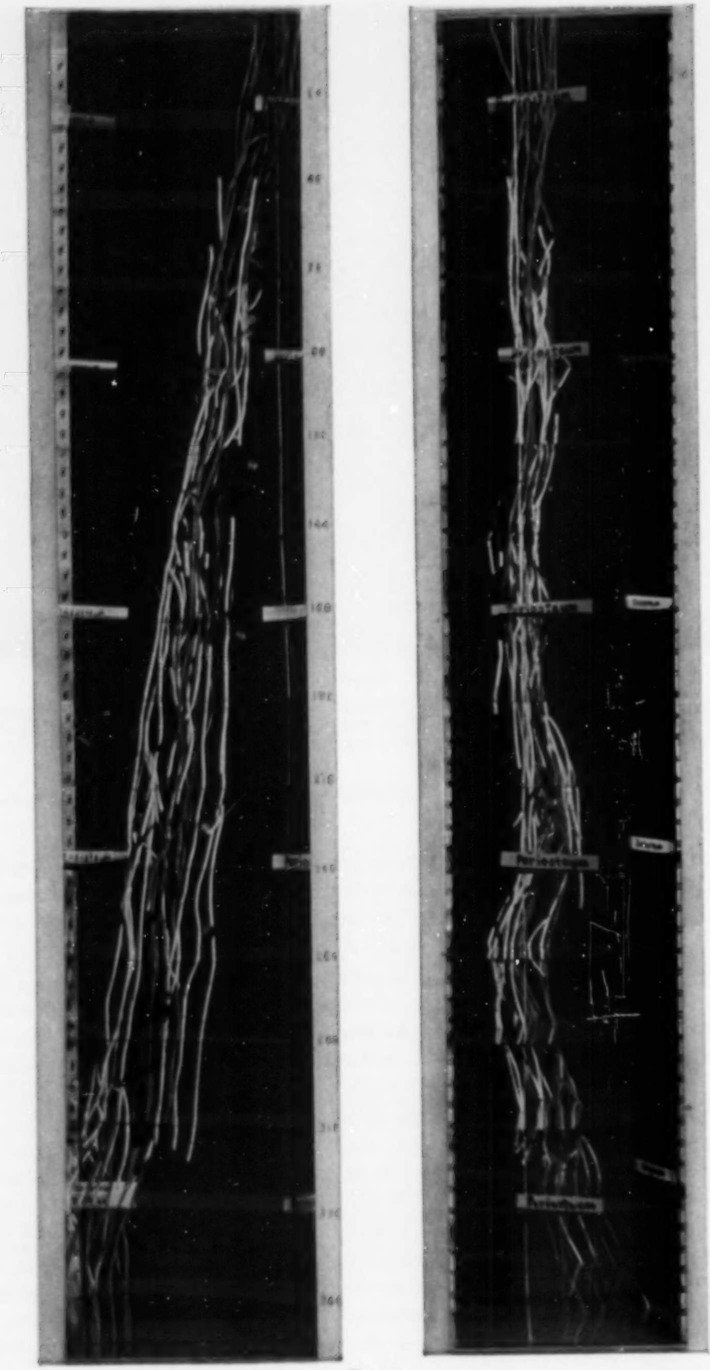
144
168
Bone
Periosteum
Bone
Periosteum

Fig. 4

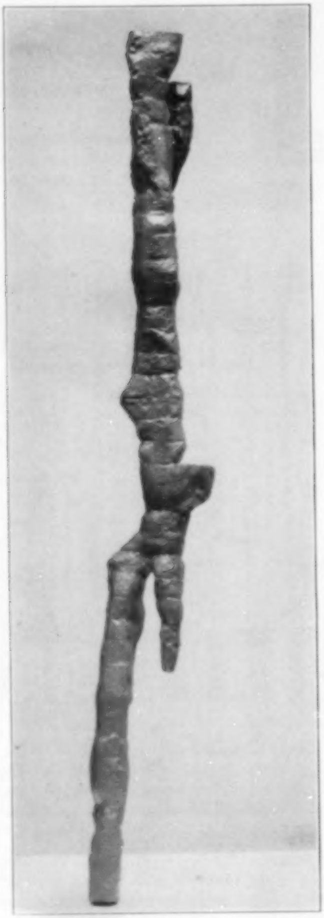

FIG. 5

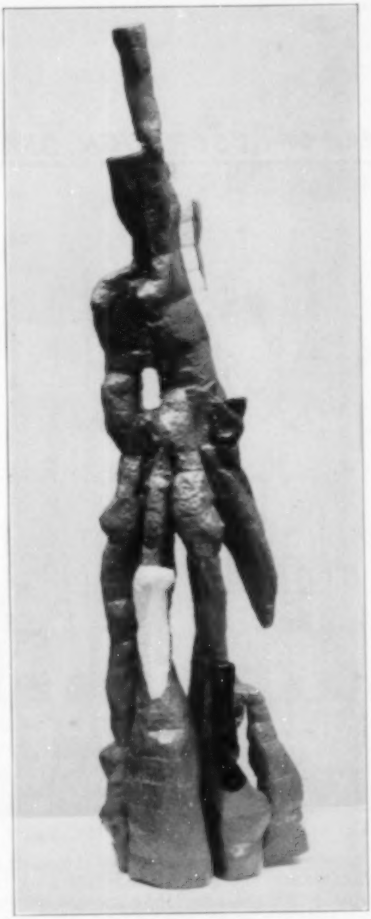

FIG. 6

Fig. 5: The simplest osteon modeled. It shows a spiral contour (two turns in 1.5 millimeters). A blindly ending osteon is present in the center. The cross-sectional area of most of the osteon is nearly the same.

Fig. 6: A model of more complex osteons. The variation in cross-sectional areas of different parts of the same osteon is evident, the enlargement occurring gradually as one goes distally. The abrupt horizontal step cuts indicate anastomoses with other (unmodeled) systems. Lesser niches and bulges characterize the external contour. A blind osteon is seen at the right.

around the axis of the bone (Figs. 1 through 4). A wide separation of the components of the network in the distal portions of the segments may be seen in the illustrations. This spread prevented accurate measurements of the slope of the spiral, since no precise point of comparison could be chosen on the distal extremity of the network comparable to the beginning of a single osteon near the periphery proximally. However, the spiral involved, at most, one-tenth of the femoral circumference.

The spreading out of the descendants of a single osteon was easily observable on the wire model. This spreading was due to two separate factors:

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Fig. 4: The wire model, anteroposterior and lateral views. The diagonal course of osteons is evident, as is their complex anastomotic network, their periosteal connections, numerous Volkmann canals, and occasional blindly ending osteons. The endosteal vascular connections are concealed by the frame. The intertwining of osteons is best shown by the red osteon in Sections 120–216. The spreading of the osteons also is easily noted when the distal and proximal parts are compared.

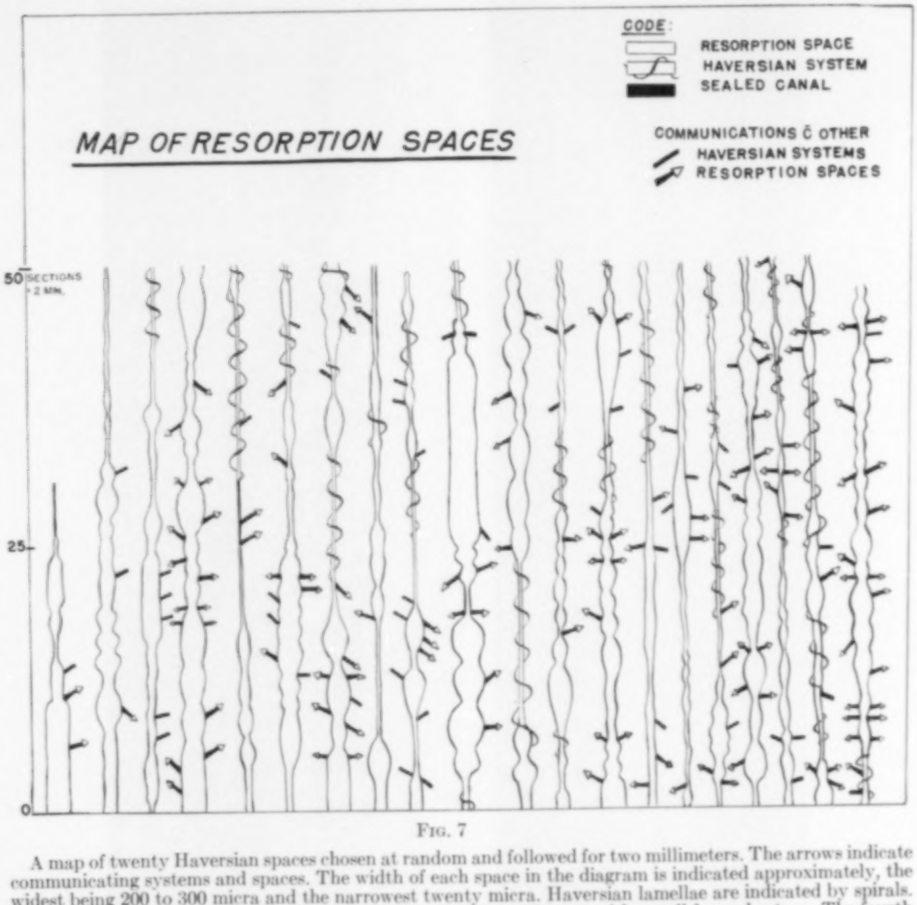

FIG. 7

A map of twenty Haversian spaces chosen at random and followed for two millimeters. The arrows indicate communicating systems and spaces. The width of each space in the diagram is indicated approximately, the widest being 200 to 300 micra and the narrowest twenty micra. Haversian lamellae are indicated by spirals. The first space ends as a sealed, blind osteon. The third is continuous with a well formed osteon. The fourth shows extreme variation in diameter of the space, while others show less variation. Despite the variation, the diameter of a space tends to persist in longitudinal extent for at least 100 micra. The fifth and sixteenth spaces are in continuity with osteons, part of whose canals are sealed. The nineteenth space shows Haversian lamellae around a large canal—an immature Haversian system. All of the spaces show communications with other spaces or systems unrelated to the variation in diameter or to other anatomical features (that is, Haversian lamellae and resorption edges).

1. Many osteons enlarged as they coursed distally and were larger in cross section near the endosteal region then they were in the subperiosteal areas (Fig. 6). Their canals, therefore, were wider apart.

2. Descendants of osteons originating in the subperiosteal area at a level distal to the group of osteons modeled, intermingled with them in the compacta, and came to occupy some of the intervening bone substance. Although many Volkmann canals established continuity of the channels of the networks arising at different levels, anastomosing between systems at the various levels was less extensive.

Another feature of the spiral arrangement of the Haversian networks was the finding that the spiralling took a clockwise direction, proceeding distally on the left femur and in a counterclockwise direction on the right. Due to the intricacy of the network, the existence of another relationship of osteons was noted occasionally, but could not be established as a general phenomenon. This was another spiral corkscrew configuration, involving a single osteon and its descendants. It was observed that the osteon nearest the subperiosteal lamellae sometimes reached the endosteal area sooner in its distal course than

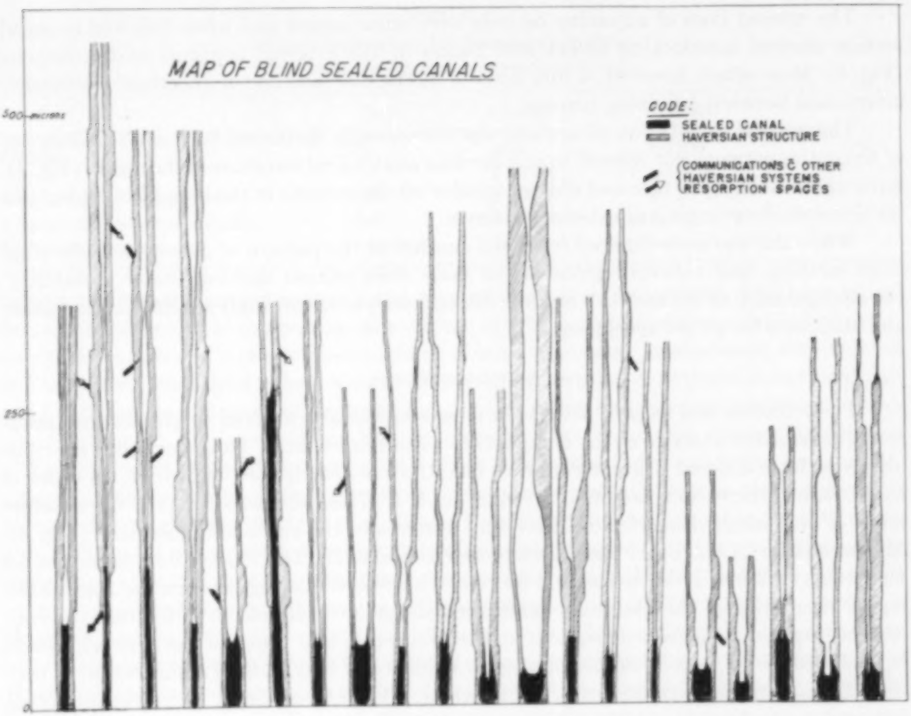
MAP OF BLIND SEALED CANALS
500-microns
250
0
CODE:
SEALED CANAL
HAVERSIAN STRUCTURE
COMMUNICATIONS c̄ OTHER HAVERSIAN SYSTEMS RESORPTION SPACES

FIG. 8

Map of twenty blind osteons selected at random. The variation in thickness of the walls of concentric lamellae in different areas of the canals is evident, as is the variation in extent of the sealed part of the canal (compare 3 with 6). Some Haversian spaces (for example 8, 12) showed sealed blind ends. No relationship between the extent of communication with other spaces or systems (arrows) and the anatomy of these blind canals could be found.

adjacent osteons more deeply placed. This finding may be interpreted as evidence that an axis to each osteon grouping exists, around which the osteons take a spiral course. This pattern may be due to artefact, attributable to the tracing of osteons predominantly in the distal direction. When osteons were traced proximally, however, they branched much less frequently, while anastomoses were more common than when they were followed distally. This fact provided some additional confirmation that the spiral components described were not artefacts.

Another relationship of osteons encountered quite frequently was irregular in distribution and configuration. This consisted in intertwining of adjoining osteons (Fig. 4). When osteons were reconstructed over many sections, the intertwining of one osteon upon its neighbor occurred as a general twist over one millimeter of the segment or more. The twisting always occurred in the same direction as the spiral orientation of the network in the specimens examined (clockwise for the left and counterclockwise for the right). The effect of this braiding, superimposed on the spiral, was to form a structure resembling a cable.

The construction of the solid models contributed one item of spatial orientation of single osteons not previously described. Single cross sections of osteons usually were oval rather than circular, and the longer diameter of successive sections often rotated a few degrees from section to section. This presented an irregular unidirectional spiral contour to the external form of the osteons (Fig. 5). The uncertainties of demarcation of the limits of many osteons, when cement-line delimitation did not exist, prevented reconstruction of this type in those instances.

The cement lines of adjoining osteons were often jagged and when followed in serial section showed interlocking niches and bulges of the external contours of the osteons (Fig. 6). More often, however, a thin layer of interstitial lamellae of uncertain orientation intervened between adjoining osteons.

The general orientation of osteons was occasionally disturbed by a mild undulation of the entire network not related to any obvious anatomical structure in the region (Fig. 4). Such undulations were rare and did not involve all the osteons in the area affected but did involve specific grouping of osteons as shown.

While the segments differed from one another in the pattern of osteons in individual cross sections, and various regions of the same cross section showed similar variability, the configuration of the network in three dimensions was surprisingly similar in orientation and structure for all six specimens.

## SIZE OF OSTEONS

The numbers and sizes of osteons in cross sections also differed so greatly that accurate quantitative analysis of the components was deemed futile. However, since previous observers have differed so greatly in their quantitative descriptions of osteons, an order of magnitude of the various factors is given in Table I. This table was obtained by measurement of one hundred unselected Haversian systems in the specimen illustrated (Fig. 4). Measurements of the other specimens were quite similar. The longitudinal extent of an Haversian system was defined as that portion of an osteon existing between the anastomosing or bifurcation of the concentric lamellated structure. It should be noted that the concept of length of osteons is dependent on the decision of how much of the network should be included, since there is no morphological evidence of longitudinal demarcation of concentric lamellae at anastomoses or bifurcations. The bifurcation of a system was often followed in two or three sections by anastomosis of the separated osteons (Fig. 6). Multiple branching of a single osteon, often into four or five descendants, also was commonly seen.

With reference to the area measurements in the table, it should be noted that the external limits of an osteon in cross section may be a poorly defined boundary, particularly if no cement line is evident and if the orientation of the cells in each area is not unequivocally concentric around the central canal. Measurements in Table I were obtained by assembling cut-outs of the Haversian systems from the photomicrographs and subsequent weighing of the assembled cut-outs. The weights were then compared with the weight of a single sheet of photographic paper, and the area thus calculated. Similar procedures were done for the largest and smallest cut-outs of each system.

Comparison of the cross-sectional areas of each osteon followed serially in the distal direction usually remained about the same or increased gradually (compare Fig. 5 with Fig. 6). Reduction in the area was rare except at bifurcations, and there the combined area of the descendant osteons was greater than that of the parent, although each descendant was smaller. This explains, in some measure, the frequency of larger osteons in the endosteal region.

The number of Volkmann-canal connections between osteons varied considerably in different individual osteons. Seemingly, the extent of an osteon before bifurcation or anastomosis had no relation to the number of Volkmann canals communicating with it. A relationship was also sought between the number of Volkmann canals and the sector of bone investigated (for example, the area near the endosteal lamellae, that near the subperiosteal lamellae, and that near the linea aspera) but none could be demonstrated.

### *Haversian Spaces*

Haversian spaces, defined as longitudinal canals of large diameter in the compacta, were also a variable feature of these several segments. Because of the thickness of the sections, it could not always be determined whether the walls of the Haversian spaces were

TABLE I

MEASUREMENTS OF 100 HAVERSIAN SYSTEMS

(One system = segment between bifurcations)

| | Unit | Average | Range | S.D. |
|---|---|---|---|---|
| Length | Mu | 480 | 1–2100 | 780 |
| Volume | $Mu^3$ | $3 \times 10^6$ | $0.1\text{–}100 \times 10^6$ | $\sim 7 \times 10^6$ |
| Area of largest cross section | $Mu^2$ | $7 \times 10^4$ | $4\text{–}23 \times 10^4$ | $3.7 \times 10^4$ |
| Area of smallest cross section | $Mu^2$ | $0.3 \times 10^4$ | $0.04\text{–}1.3 \times 10^4$ | $0.3 \times 10^4$ |
| Volkmann canals | Number | 1 | 0–8 | 1.9 |

eroded or whether they were smooth and covered by a layer of new bone. This histological feature is the principal morphological evidence of whether absorption or deposition is occurring in the area of interest. Since surfaces of both types were encountered, the evidence did not allow conclusions to be drawn as to whether absorption or deposition was predominant. All degrees of transition between mature Haversian systems and resorption spaces could be seen. In the femora of one dog, spaces were found in greater number than in any of the four other segments examined. An effort was made to determine the longitudinal extent and relationships of the spaces in all six segments. As with osteons, the spaces could be traced through many sections (Fig. 7), and frequently an intermittent variability in the size of the canal was evident. The channels which anastomosed with the resorption spaces more often than not were also resorption spaces. Examples of the intermittency of an Haversian space could be seen alternating with an osteon of more mature structure. However, Haversian spaces were often continuous channels over a few millimeters. The occasional intermittency was never confined to a small number of sections, and the alternation of Haversian spaces and osteons in continuity nearly always involved segments of irregular length, always more than 100 micra. Since these measurements of the longitudinal extent of Haversian spaces become important in consideration of serial autoradiographs of $Ca^{45}$, Figure 7 shows a map of a number of these spaces and their measurements and connections. The location of Haversian spaces within sectors of single sections in the several segments proved to be variable from segment to segment, but most often they were found at the junction of the subperiosteal lamellae with the Haversian portion of the compacta, or at the junction of the subendosteal lamellae with the Haversian area of the compacta. Scattered Haversian spaces could be found, particularly in the region of the linea aspera, but the areas where Haversian spaces were least frequent were the circumferential lamellae immediately subperiosteal. The shape of Haversian spaces usually was irregularly cylindrical. The resorption spaces were lined by loose collections of fibroblasts and osteoblasts in the center of which were a few thin-walled sinusoids. Occasionally, resorption spaces had portions which were flattened, the cross sections measuring approximately 100 by twenty micra. The flattened portions were usually directed axially, and circumferentially, and persisted only for one or two sections. Transversely flattened resorption spaces, when present, were sites of anastomoses of two or more axially directed resorption spaces.

### *Formation of Osteons*

One of the striking findings of this study stems from an initial observation that the canal of one of the eight osteons selected for modeling, when traced proximally, lost its investing lamellae and became a longitudinal canal between circumferential lamellae. Since numerous systems, as well as canals, could be found sandwiched between layers of circumferential lamellae (Fig. 3), it was of interest to discover that axial tracings of this osteon and canal through the serial sections revealed intermittent areas in which the concentric lamellae were present, alternating with some where the canal was uninvested. Through these expanses, the canal usually remained unbranched. Numerous instances of this intermittency were encountered in the subperiosteal lamellae. In the subendosteal lamellae, the same process was evident, although less commonly. When the osteon reached the intermediate (Haversian) part of the compacta, the intermittency was no longer evident, since canals uninvested by concentric lamellae were not found coursing longitudinally in this sector. The number of sections through which vessels coursed intermittently invested by concentric lamellae was quite variable, and averaged between 0.5 millimeter and two millimeters in total thickness. The area of investment and non-investment of concentric lamellae also varied in axial measurements. Spotty and very short sections of either structure were not observed, and one or the other pattern persisted through many sections. Although the same pattern could be demonstrated in the subendosteal lamellae, fewer instances of intermittent concentric investment of canals were seen, primarily because of the more rudimentary structure of the subendosteal lamellae in the segments examined. In contrast, subperiosteal lamellae were always present in these segments to some degree and often occupied three-fourths of the circumference of the bone and up to one-third of its thickness.

### *Blind Osteons*

Some osteons tapered slightly and ended blindly, that is, without communication with other systems. These blind osteons were directed distally or proximally, and their numbers varied considerably in the different specimens (Fig. 8). Their canals or vessels did not progress beyond their concentric lamellae. Blind osteons characteristically ended in areas of interstitial lamellae and not in the substance of intact osteons.

Often, the Haversian canals in blindly ending osteons were filled throughout their terminal fifty to 200 micra with material staining like bone. Occasionally an osteocyte in a lacuna was observed in the terminal portion of such a sealed Haversian canal. The terminal portion of the canals of sealed osteons, and also their sealed area, stained deep purple with hematoxylin.

### *Interstitial Lamellae*

Several reconstructions demonstrated clearly that most individual blocks of interstitial lamellae were structurally continuous with osteons, either distally or proximally. The junctions occurred in areas where there was an anastomosis of two osteons. The morphology there indicated that the formation or revision of the anastomosis resulted in resorption of one side of a segment of osteon, the remaining part appearing in cross section as interstitial lamellae. Occasionally, blocks of interstitial lamellae were continuous with blind osteons having sealed or patent canals. Other blocks of interstitial lamellae, by their orientation, were remnants of subperiosteal circumferential lamellae.

In those segments of femur composed in large part of subperiosteal circumferential lamellae, the intermediate (Haversian) part of the compacta contained many remnants of circumferential lamellae, and few lamellar remnants of concentric (as opposed to circumferential) type could be seen. In other segments, where the compacta showed mainly well defined Haversian systems, large blocks of interstitial lamellae of a concentric type were present. Surrounding each Haversian system, particularly observable with the phase microscope, one often found a thin (five to twenty micra) area of bone substance containing cells and lamellae whose orientation was poorly defined, although when stained the bone substance did not show significant variation from the adjoining concentric lamellae of the osteon.

The connection between periosteal vessels and subperiosteal axial vessels was usually of small caliber, and rather less frequent than the vascular connections between subendosteal channels and the marrow space. There was a marked variation in the number of periosteal and endosteal communications. At the endosteum, in nearly all cases, the vascular channels were two to four times the caliber of the periosteal vessels. Frequently, a build-up of bone on either side of the vascular channel by subendosteal circumferential lamellae could be found to enclose the channel further along on the segment, proximally or distally, thus establishing a structural continuity of the Haversian system with the subendosteal lamellae.

## DISCUSSION

The structure of Haversian systems, as illustrated by the three-dimensional reconstruction, is significant mechanically and biologically. From the mechanical point of view, it is evident that the spiral conformations described may be an essential factor in the explanation of the unusual mechanical properties of bone. The frequent spiral or oblique fracture of some long bones, the different mechanical properties of bone substance as revealed by blocks taken along different directions relative to the axis of the bone, and the difficulty in sectioning bone crosswise, as compared with sectioning longitudinally, may all arise in part from these structural features. From the mechanical point of view, the orientation of the network of osteons in a specimen must be taken into account wherever bone substance is subjected to testing procedures, for example, for tensile strength, modulus of elasticity, and fatigue strength. Bone substance may no longer be viewed structurally with respect only to fibers and crystals and their ultramicroscopic orientation as derived from small samples, but more as a complex fabric with larger units of organization superimposed on the smaller. Test specimens must take into account these larger units of organization. The situation is analogous to that of the testing of metals, in which changes in size, shape, and orientation of granules may change the mechanical properties of the material, even though the composition and crystalline elements are unchanged. The lamellae of bone, circumferential, interstitial, and concentric, are thus mechanically important units of organization, and the osteons in particular provide a mechanically significant pattern of continuity and orientation.

While it is obvious that the spiral orientation found in this study may be relevant only to part of the dog's femur, and even here the number of segments examined may be inadequate for confident generalization, the existence of such a pattern raises the possibility that this or other patterns may be of importance in other locations in bone. This possibility was raised by Koltze, whose careful reconstruction of part of a human phalanx has been alluded to previously. While he did not recognize a spiral patterning, he did record several observations and conclusions which are well confirmed in this study. The continuity of interstitial lamellae with well formed osteons, the continuity of subendosteal lamellae with osteons, the enlargement of cross sections of the osteons during their course in the bone substance or at bifurcations were all noted in his report and are confirmed here. The work of Filogamo, while primarily concerned with the average height of osteons in man and various animals according to age, must also be cited, since many of the details which have been described are referred to in his report. Koltze discussed, at length, the points of similarity and divergence between his work and that of Filogamo, Amprino, Petersen, and Schumacher. The reader is, therefore, referred to Koltze's splendid publication, in which a review of the pertinent literature may be found.

Koltze was able to show continuity between osteon and spongiosa walls of the metaphysis, because his specimen, the distal segment of a phalanx, included metaphysis as well as diaphysis. The bone structure he modeled, therefore, was the transition between compacta and spongiosa, and it provided some interesting contrasts with the diaphyseal segments reported in this study. Osteons, which Koltze traced toward the diaphysis, that is, proximally, showed branching much more commonly than those followed toward the epiphysis. In the present study, the same patterns were present when the serial sections were traced distally. Since the femoral diaphysis in its distal portion was not studied, nor was the proximal portion of Koltze's phalangeal specimen, it is not known whether the patterns of branching hold throughout the bone or are reversed in the other halves of these bones. The importance of this question is obvious when one attempts to correlate, etiologically, the patterns of branching with developmental or vascular or mechanical factors.

From the mechanical point of view alone, the branchings of osteons must have significance, as Koltze stated, and before him, Schumacher. Other factors of theoretical importance shown in this study are:

1. Spiral orientation of the osteons' network with relation to the axis of the femur;
2. The spiral orientation of individual osteon families on their own axes;
3. The twisting of individual osteons upon one another;
4. The spiral and irregular contour of the external surface of osteons so that the irregularity of one osteon may fit into corresponding irregularities in an adjoining osteon.

The mechanical properties of bone substance, no doubt, are also influenced by other structural elements at the microscopic level, such as the circumferential and interstitial lamellae, and, at the ultra-microscopic level, by the number, type, orientation, dimensions, and interrelations of fibers and crystals. The intra-osseous vascular pattern has been known to be one of rich anastomosis, and the present demonstration does not differ substantially from that of Schumacher in 1935. Only a few new details may be worth calling attention to. One is the large number and size of channels at the endosteum communicating with the marrow. The uniformly thin walls of nearly all vessels (sinusoids) in Haversian and Volkmann canals do not permit one to infer the direction of blood flow in bone substance. If the general rule holds that veins are larger and more numerous than the corresponding arteries, this may indicate that in the compacta the flow is from periosteum to endosteum. The absence of a muscular coat to the vessels, the rigidity of the canal walls, and the absence of venous valves also may suggest that the course and volume of blood flow in bone is more influenced by pressure changes in the soft tissues and marrow than by intraosseous factors and may be reversed with appropriate changes in these pressures. The nutrient arteries are not included in this statement —they have a well defined muscularis, but do not supply direct branches to the bone substance.

The manner of formation of Haversian systems may be considered next. It is generally conceded, from morphological data, that osteons are formed by slow concentric deposition of layers of bone substance in an Haversian space. One would anticipate that the three-dimensional pattern of Haversian spaces would correspond in general with that of osteons, which was shown to be the case in this study. Whether a single Haversian system is formed as a unit, continuous spatially and temporally, or whether there is intermittency in its formation is a question to which this study contributes pertinent data. Spatial intermittency of concentric lamellae was found to occur in relation to axially directed vessels in the circumferential lamellae subperiosteally. Similar spatial intermittency was noted in the alternation of resorption spaces and mature or partially formed osteons, the latter being those possessing some concentric lamellae around large canals. Since the intermittency in each instance involves a considerable axial length of each component, that is, 100 micra to one millimeter or more, the factors governing the process must operate over distances of that order of magnitude. The implication is that it is likely that the activities of individual cells, whether of the connective tissue or endothelium, are regulated in groups by chemical factors, although mechanical influences still may play a role. The considerable variation in the thickness of walls of osteons at different levels and the intermittency and variation in thickness of concentric lamellae around resorption spaces, also speak for a discontinuous rate of formation of different parts of single osteons, with respect to time. Since lamellae of Haversian systems usually are not well delineated morphologically, the number of concentric layers, either of cells or of bone substance in serial sections, can only be compared in a general way, and the shape and cross-sectional areas of osteons and their canals provide a more accurate measure of comparison.

By these comparisons, it has been shown that when an osteon increases its cross-sectional area, despite the observed increase in the number of rings of cells or lamellae, there is no indication of discontinuity in the section where the additional lamellae or cells first are seen. This is true not only for the external contour of osteons, where the additional lamellae, while parallel, vary in the extent of their arcs, but also for the lamellae forming the inner walls of those resorption spaces which showed progressive narrowing of their canals. Where one or more concentric cement lines exist in the walls of an osteon, the temporal discontinuity in deposition they represent must, therefore, be of a larger order of magnitude. It is quite probable, therefore, that lamellae may be joined to one another after shorter lapses in deposition without cement-line demarcation.

Discontinuities in bone deposition, therefore, probably occur within single osteons as a general phenomenon. Variations in rate of bone deposition in osteons also may be anticipated and offer good subjects for isotopic techniques of investigation.

The frequent occurrence in some segments of blindly ending osteons with filled-in canals, the center staining deep purple with hematoxylin and eosin, deserves attention. As far back as Tomes and DeMorgan (1853), this observation has been recorded, but given little attention. Its importance rests in the manner of filling of such a blindly ending canal with relation to blood flow. Sinusoids often are absent in the terminal portion of the canal, where only an occasional marrow cell may be seen. The canal may course, thus, through 100 micra or more containing no blood vessels and the filled-in portion may extend even farther. We may assume that the filling-in process occurs in relation to the osteoblasts at a significant distance from blood vessels. When the active process of filling-in stops, the cellular and vascular contents of the terminal portion of the canal may disappear, leaving it empty of cellular elements.

The blind ends of osteons often occurred in remains of subperiosteal or concentric lamellae. Their probable manner of formation was by longitudinal extension of an Haversian space or system by means of blood vessels burrowing into these lamellae, followed by successive deposits of concentric lamellae until the osteon was complete. An alternative method of formation of blind osteons is by resorption of a mature osteon, at one point in its course, by an Haversian space crossing its path, without the formation of an anastomosis between the sinusoids in the resorption space and the osteon's canal. The canal of the blind osteon may then fill in or remain patent, while in the resorption space a new osteon may form. In the material examined, filled-in canals and patent blind canals were frequently observed, often in continuity with interstitial lamellae.

The importance of the continuity of the osteons and interstitial lamellae is that, anatomically, an axial pathway is provided for diffusion of fluids through most of the compact bone. The concentric orientation of osteocytes around the central canal of the osteon and the interconnecting canaliculi seen in cross section, previously favored a centrifugal or centripetal route for this diffusion and calculations have been made on this basis to determine the maximal distance possible between osteocyte and vessel. If a longitudinal pathway also exists, comparable to a resin column for diffusion of fluids, with or without the mediation of cells, it is much more compatible with the predominantly axial orientation of fibers, crystals, and lamellae in bone.

Another inference to be drawn from the relationships between interstitial lamellae and adjoining Haversian systems is that the anastomotic network does not remain static. It should be emphasized that as part of the process of remodeling, revision of anastomosis occurs, either by addition of new communications, by obliteration of old ones, or by transposition of some osteons' communications, either proximally or distally. The latter process results in complex lamellar patterns at points of anastomosis, with blocks of interstitial lamellae in continuity with the intact osteons at their bifurcations.

The dark staining reaction to hematoxylin of cement lines and of the innermost borders of those Haversian canals which, further in their course, show filling of the blind ends, is similar to that of the filling substance, and deserves the attention of histochemists, since similar changes have led to important findings concerning the polysaccharides and mineral concentration of such regions.

The geography of Haversian spaces and osteons assumes added importance when the distribution of radioactive isotopes in compact bone is considered. Unreported work from this laboratory has shown concentration of $Ca^{45}$ occurring in nearly all Haversian spaces twelve hours after intravenous administration. The frequency of these Haversian spaces at their sites of predilection, the internal limits of the subperiosteal circumferential lamellae, the linea aspera, and the spotted areas in the Haversian compacta, indicate the need for further investigation of the pattern of formation and replacement of Haversian systems.

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# Inhibition of Estradiol-Induced Endosteal-Bone Formation After Intrafemoral Implantation of Testosterone Propionate Into Mice*†

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Estrogens induce endosteal-bone formation in vertebrates, with evidence indicating that these hormones stimulate osteoblasts and inhibit resorption of bone[6, 8, 11]. On the other hand, testosterone propionate, when given systemically, inhibits the osteogenetic actions of estrogens[5, 7, 9, 10, 18].

In studies on the local effects of estrogens on bone, two divergent conclusions have been drawn: (1) intramedullary applications of estrogens to bones induced local hyperostosis with little change in the untreated bone[1, 2, 9, 10]; (2) intramedullary or topical applications of estrogens to bones show systemic effects of osseous proliferations in bones in addition to bone formation in treated bones[3, 11, 16].

Because studies have already been made on the systemic effects of testosterone propionate and estrogen given simultaneously, the present investigations were made to determine the effects of intramedullary applications of testosterone propionate with systemic implantations of estrogen. Secondly, experiments were designed to clarify the effects of the local application of estrogens to hyperostosis.

## MATERIALS AND METHODS

One hundred sixty-seven $C_{57}$ mice, seventy to seventy-five days old, were used in this study. Their right femora were exposed by incisions of the medial portion of the thigh and blunt dissections of muscles. Small cavities were made with a dental drill into the distal one-third of the femora. With the exception of the mice of two groups, pellets of hormones or placebos were deposited into the femoral cavities.

Fused pellets were made by heating three parts of cholesterol to one part steroid hormone. Pellets containing approximately eighty to ninety micrograms of hormones were used. Compressed pellets of pure testosterone propionate or cholesterol were made in a pellet press[4] and broken into average weights of two milligrams. Mice were arranged in seven groups and received the treatment described in Table I.

Necropsies were performed at weekly intervals for four weeks. Both femora from each mouse were fixed and decalcified in modified Bouin's fluid (eighty-five milliliters of saturated picric acid, five milliliters of 90 to 95 per cent formic acid, and ten milliliters of 40 per cent formaldehyde), dehydrated and embedded by the dioxane-paraffin method, treated with either Harris' hematoxylin and eosin stain or with the Dominici stain.

## OBSERVATIONS

At necropsy, subcutaneous pellets of estradiol benzoate were found in all mice. The pellets implanted in the femora were observed grossly in a number of mice. Intrafemoral pellets were dissolved during the staining process, but the position of the pellets was indicated clearly by the distribution of surrounding osteoblasts or trabeculae.

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* Results read at the Annual Meeting of the American Association of Anatomists, Milwaukee, Wisconsin, April 6, 1956.

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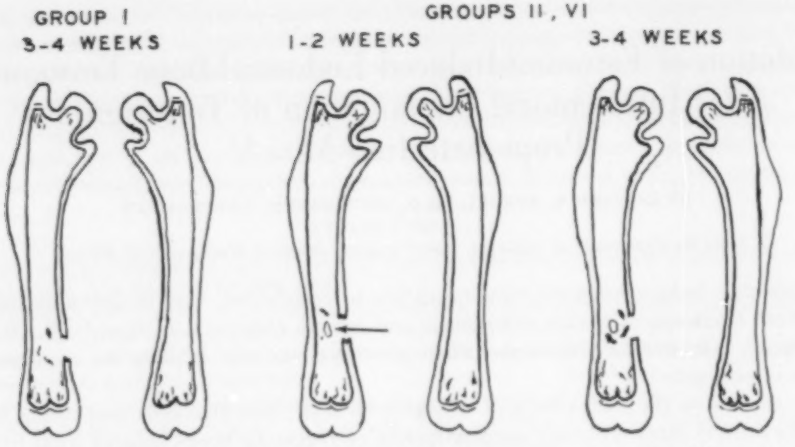

Fig. 1-A Fig. 1-B Fig. 1-C

Fig. 1-A: Diagram of femora from Group I. A hole was drilled in the distal third of the right femur three to four weeks before necropsy. Little metaphyseal proliferation of bone occurred and no sealing callus had formed. The untreated contralateral femur to the right showed a normal distribution of osseous metaphyseal trabeculae.

Figs. 1-B and 1-C: Diagrams of femora from Groups II and VI. The right femur was implanted with two-milligram pellets of testosterone propionate or cholesterol (arrow). Only a few osseous spicules are in the marrow cavity at the traumatized site, and the metaphysis is not proliferated with trabeculae. The untreated femur to the right showed a distribution of metaphyseal spicules similar to that in Group I.

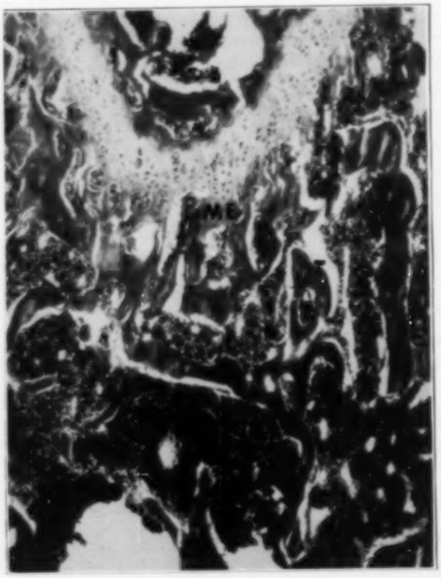

Fig. 2-A

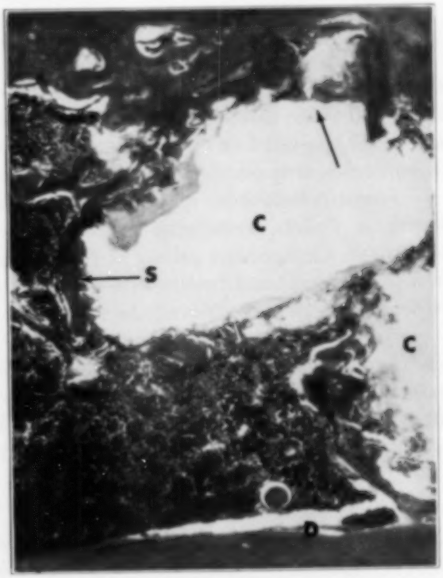

Fig. 2-B

Fig. 2-A: Distal metaphyseal-epiphyseal junction (*ME*) from the right femur of a male mouse implanted with a two-milligram cholesterol pellet for four weeks. A normal amount of trabeculae (*T*) comprised the metaphysis. Red marrow was abundant between the trabeculae (× 65).

Fig. 2-B: The cholesterol pellet implantation site from the same femur seen in Fig. 2-A. A few spicules of bone (*S*) surrounded the site of the cholesterol pellet (*C*). The hole drilled into the diaphysis (arrow) has been closed off by a uniting callus. Note that red marrow was present between the pellet site and the diaphysis (*D*) opposite the drilled area (× 65).

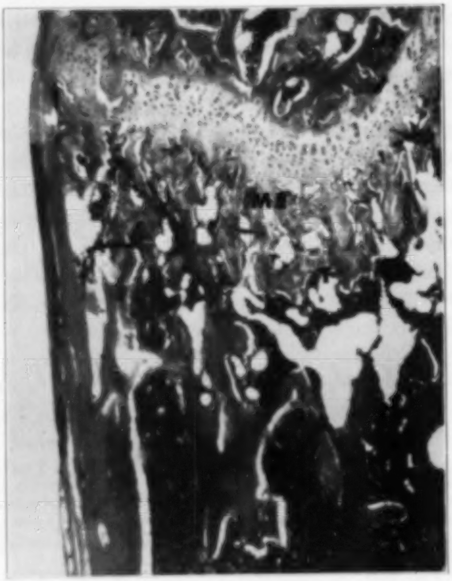

Fig. 3-A

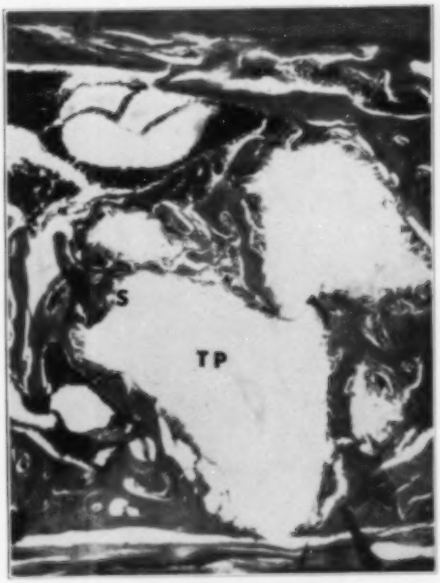

Fig. 3-B

Fig. 3-A: Distal metaphyseal junction (*ME*) from the right femur of a male mouse implanted with a two-milligram testosterone propionate pellet. A normal amount of metaphyseal trabeculae (*T*) was present, so that testosterone propionate neither inhibited nor stimulated endosteal ossification (× 65).

Fig. 3-B: The testosterone propionate site from the same mouse femur as in Fig. 3-A. Thin spicules of bone (*S*) surrounded the site of the testosterone propionate pellet (*TP*). Note the similarity between this figure and Fig. 2-B (× 65).

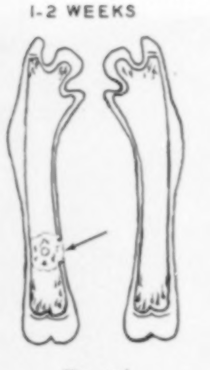

Fig. 4-A

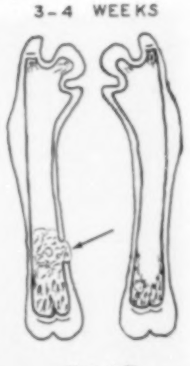

Fig. 4-B

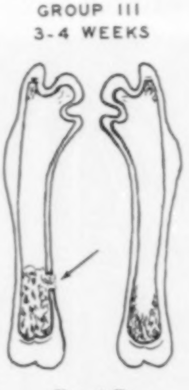

Fig. 4-C

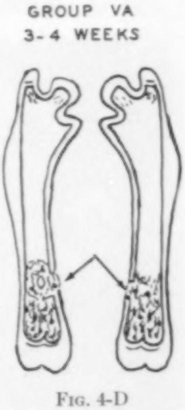

Fig. 4-D

Fig. 4-A and 4-B: Diagrams of femora from Groups IV and V. The right femur was intrafemorally implanted with a cholesterol pellet in addition to a subcutaneously placed estradiol benzoate pellet (Group IV), or it was implanted with an estradiol benzoate pellet (Group V). After one to two weeks, implanted femora had fibrocartilaginous to osseous callus deep into the drilled site (arrow) with some proliferation of spicules at the distal metaphyses. By the third and fourth weeks, metaphyseal bone trabeculae coalesced and united with the sealing callus. Contralateral femora had as intense endosteal ossification as the drilled femora but it did not extend as far proximally.

Fig. 4-C: Diagram of femora from Group III. The right femur was drilled in the distal third of the bone (arrow), and the mouse was given a subcutaneous implantation of a ninety-microgram pellet of estradiol benzoate. Endosteal-bone formation was greater in the drilled bones than in the contralateral femora.

Fig. 4-D: Diagram of femora from Group V-A. These mice had both femora drilled (arrows) with endosteal benzoate pellets placed only in the right femora. Endosteal ossification in both femora was similar.

With the dosages of hormones given, no sex differences in bone changes were observed, since osseous responses were highly variable in each sex. Furthermore it was not possible to differentiate between hormone-treated bones of castrated and non-castrated mice.

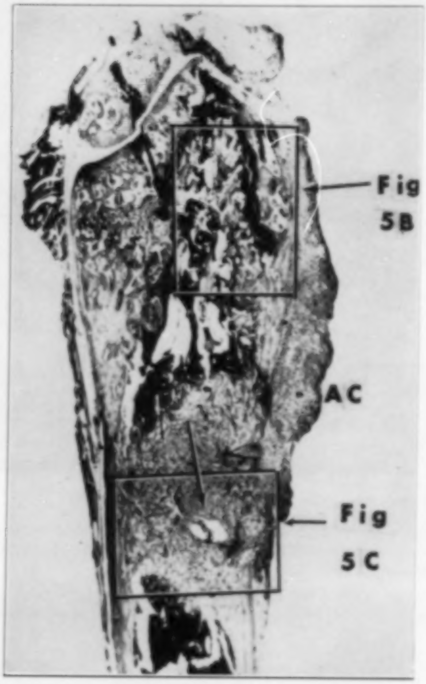

FIG. 5-A

Bone callus was divided into specific regions and defined as follows[14]: *anchoring callus* is the callus surrounding the drilled site of the femur; *bridging callus* is the continuation of the anchoring callus over the drilled site; *uniting callus* is part of the callus which fills the drilled site; *sealing callus* is the callus that replaces the marrow cavity deep into the drilled site.

*Groups I, II, and VI*

Each of the mice in these groups had a

Fig. 5-A: Distal half of a right femur from a castrated male mouse implanted for one week with a pellet containing ninety micrograms of estradiol benzoate. Sealing callus surrounded the pellet site (arrow). In this case, the femur had, in addition, anchoring and bridging callus (× 20).

Fig. 5-B: Metaphyseal-epiphyseal junction of the same femur seen in Fig. 5-A. The metaphysis (*M*) adjacent to the epiphysis (*E*) was beginning to coalesce and obliterate the trapped marrow (× 65).

Fig. 5-C: Callus and estradiol benzoate pellet site (*EB*) from the same mouse femur as in Fig. 5-A. Trabeculae were interspersed with the fibrocartilage and surrounded the estrogen-pellet site from the drilled site to the opposite diaphyseal shaft (*D*). Note that the uniting callus (*UC*) completely filled the drilled hole in the diaphysis and had overgrown outside of the diaphysis as the anchoring (*AC*) and bridging callus (*BC*) (× 65).

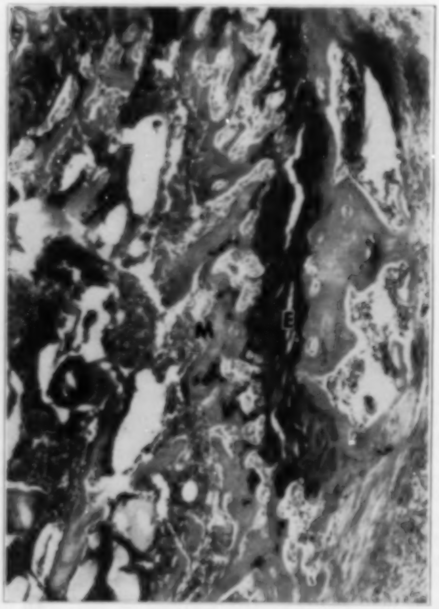

FIG. 5-B

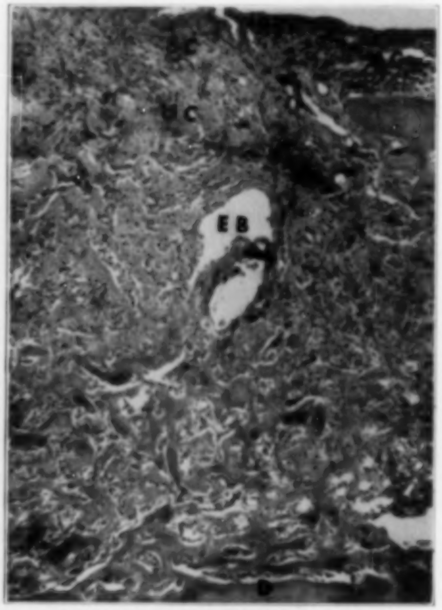

FIG. 5-C

hole drilled in its right femur. Some received no subsequent treatment, while in others a pellet of cholesterol or testosterone propionate was placed intrafemorally (Fig. 1). The drilled sites of the femora had uniting callus which ossified by four weeks. However, in some femora, uniting callus did not close the drilled cavities. Pellets were usually surrounded by hematopoietic elements and bone trabeculae (Figs. 2-B and 3-B). Sealing callus was composed of ossified spicules interspersed with islands of red marrow. The remaining parts of the bone were similar to the contralateral femora (Figs. 2-A and 3-A). In the contralateral femora, the distal ends of the bones had epiphyseal-cartilage plates with cells arranged in a columnar manner. The metaphyses were composed of a few bone trabeculae and central cartilaginous matrices near the epiphyses. The diaphyses were filled with red marrow, containing a few or no spicules of bone. The proximal metaphyses were composed of bone trabeculae in relation to the proximal epiphyses, and continuous with trabeculae in the necks of the femora.

Fig. 6-A: Distal half of the right femur from a castrated male mouse implanted with a ninety-microgram estradiol benzoate pellet for four weeks previous to necropsy. The callus surrounding the pellet site (arrow) was continuous with coalesced trabeculae, with the concomitant loss of the marrow cavity distal to the implantation site (× 22).

Fig. 6-B: Distal metaphyseal-epiphyseal junction (*ME*) of the same femur as in Fig. 6-A. The metaphysis was now comprised of heavy coalesced trabeculae. Some red marrow was present between the trabeculae (× 65).

Fig. 6-C: Callus and estradiol benzoate pellet site (*EB*) from the same mouse femur as in Fig. 6-A. The callus was completely ossified and the trabeculae were wide and coalesced similarly to the epiphyseal-metaphyseal junction (× 65).

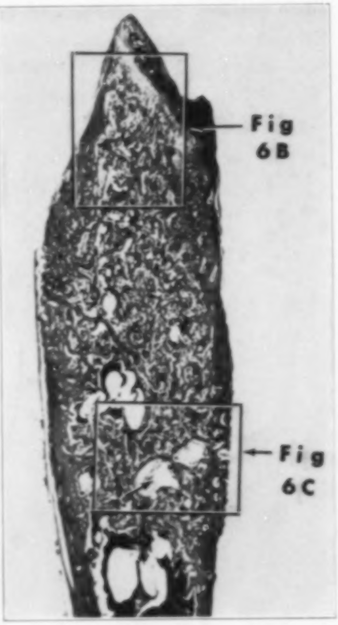

FIG. 6-A

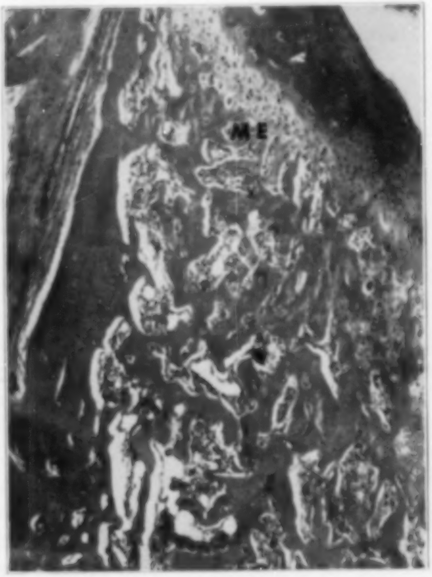

FIG. 6-B

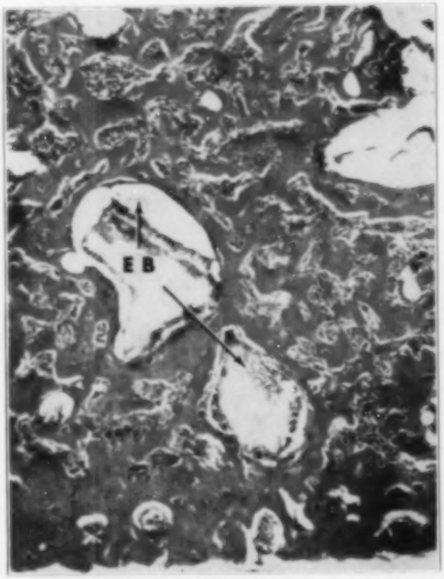

FIG. 6-C

*Groups III, IV, and V*

A hole was drilled in the right femur of each mouse (Fig. 4), and each received either a subcutaneously implanted pellet of estradiol benzoate or an intrafemorally placed pellet of cholesterol or estradiol benzoate.

*One Week:* In the implanted femora (Figs. 4 and 5-A), the drilled sites were filled with uniting callus and the adjacent marrows were replaced by sealing callus composed of fibrocartilage and spicules of bone surrounded by many osteoblasts particularly in the area of the pellets (Fig. 5-C). Anchoring callus, containing hypertrophied chondrocytes and different amounts of osseous tissues, surrounded the periosteal areas of the lesions. The callus did not separate the marrow proximal and distal to the drilled sites. The distal portions of the metaphyses had more trabeculae than those from mice treated with either cholesterol or testosterone propionate (Fig. 5-B). The remaining parts of the femora were normal. In the contralateral femora, the metaphyses had increased numbers of both osteoblasts and bone trabeculae similar to the drilled femora. The proximal three-fourths of the bones was normal.

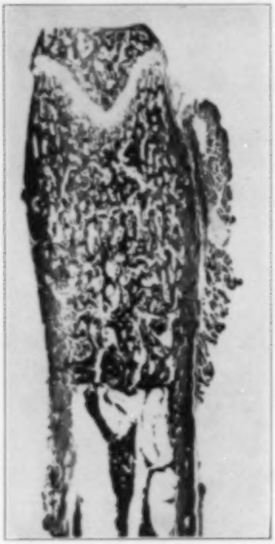

Fig. 7

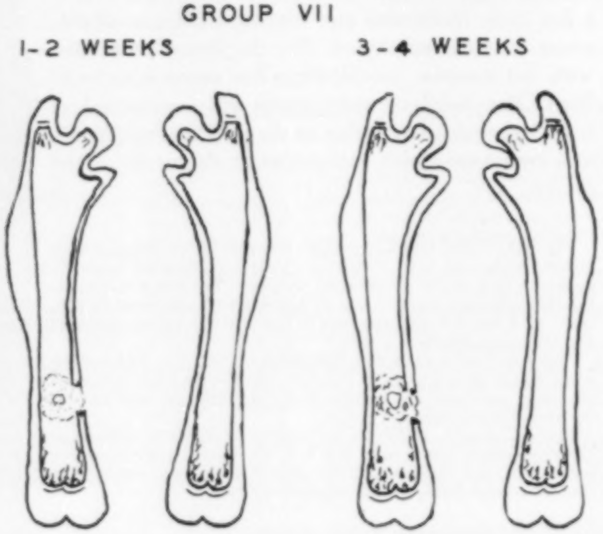

Fig. 8

Fig. 7: Distal half of an unimplanted femur from a castrated female mouse with a ninety-microgram pellet of estradiol benzoate implanted in the contralateral femur for four weeks previous to necropsy. The trabeculae were fused with a loss of the marrow cavity in the distal portion of the femur (× 20).

Fig. 8: Diagram of femora from Group VII. The right femur had a two-milligram pellet of testosterone propionate implanted intrafemorally and a ninety-microgram estradiol benzoate pellet given subcutaneously. This showed testosterone propionate inhibition of estradiol-induced endosteal ossification at the distal metaphyses.

*Two weeks:* Femora were similar to those at one week except that the osseous trabeculae in the metaphyses were larger and more numerous in both the treated and contralateral femora. In the treated femora, sealing callus was larger and contained more bone than at one week.

*Three to four weeks:* The osseous trabeculae of the metaphyses and the callus at the traumatized areas had coalesced in the drilled femora (Figs. 6-A, 6-B, and 6-C); the remaining intertrabecular spaces had filled with osteoblasts and blood vessels. The marrow was replaced by bone distal to the drilled hole in some animals at three weeks. By four weeks, hematopoietic tissue in that region was absent in nearly all the femora. The anchoring and bridging callus became larger over and around the drilled sites. The remote areas of the femora were unaffected. In the contralateral femora, the trabeculae of the metaphyses were coalesced and extended proximally about one-fourth of the lengths of the femora (Fig. 7). In addition, two males and two females had both femora drilled, but estradiol benzoate pellets were placed only in the right femora. At four weeks, the contralateral or left femora appeared similar to the treated ones (Fig. 4, Group V-A). Therefore, trauma greatly accentuated bone formation even in the non-implanted femora.

### *Group VII*

After intrafemoral implantations of pellets containing eighty micrograms of testosterone propionate along with subcutaneous implantations of pellets containing ninety micrograms of estradiol benzoate, drilled and contralateral femora resembled those of mice given estradiol benzoate alone.

After implantations of approximately two-milligram pellets of testosterone propionate in the femoral

Fig. 9-A: Distal half of the right femur of a castrated female into which was implanted intrafemorally a two-milligram pellet of testosterone propionate and a ninety-microgram estradiol benzoate pellet was placed subcutaneously. Sealing callus surrounded the androgen-pellet site (arrow). There was well developed anchoring (*AC*) and bridging callus (*BC*) present in this femur (× 20).

Fig. 9-B: Metaphyseal-epiphyseal junction of the same femur as in Fig. 9-A. This showed the inhibition of estradiol-benzoate-induced endosteal ossification in the region of the metaphysis. The latter was composed of a broader band of trabeculae than the cholesterol or testosterone propionate treated mice femora (Figs. 2-A and 3-A), but much narrower than the estradiol benzoate treated mice femora (Figs. 6-A and 6-B) (× 65).

Fig. 9-C: Callus and testosterone propionate pellet site (*TP*). The sealing callus (*SC*) was composed of several trabeculae of bone surrounding the pellet site. Note the well developed bridging callus (*BC*) (× 65).

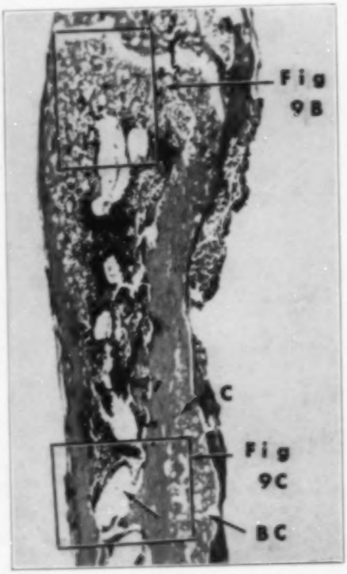

FIG. 9-A

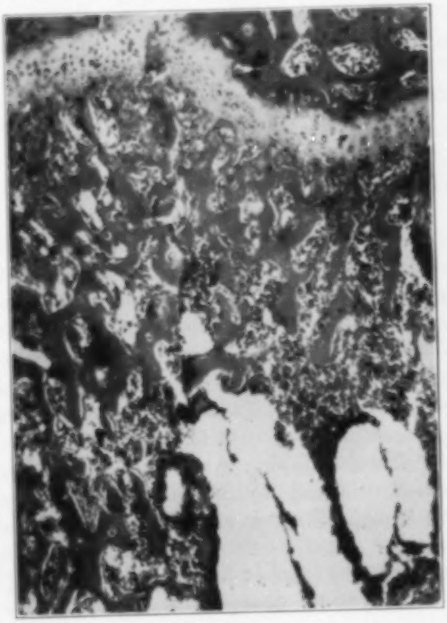

FIG. 9-B

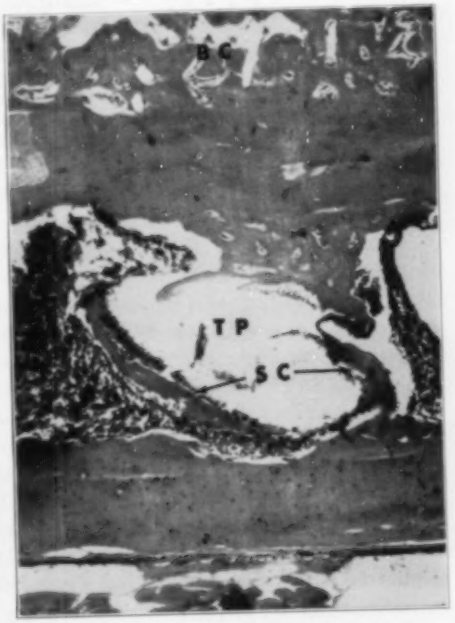

FIG. 9-C

TABLE I
TREATMENT OF THE MICE

| | No. and Sex | Treatment | Time of Sacrifice (*Weeks*) |
|---|---|---|---|
| Group I | 5 ♂, 4 ♀ | Right femur drilled; no pellet | 4 |
| Group II | 2 ♂, 2 ♀ | Two-milligram cholesterol pellet implanted into right femur | 2 |
| | 5 ♂, 5 ♀ | Two-milligram cholesterol pellet implanted into right femur | 4 |
| Group III | 3 ♂, 2 ♀ | Right femur drilled; ninety-microgram estradiol benzoate pellet implanted subcutaneously | 4 |
| Group IV | 5 ♂, 5 ♀ | Two-milligram cholesterol pellet implanted into right femur; ninety-microgram estradiol benzoate pellet implanted subcutaneously | 4 |
| Group V | 5 ♂, 5 ♀<br>6 ♂*, 6 ♀* | Ninety-microgram estradiol benzoate pellet implanted into right femur | 1 or 2 |
| | 6 ♂, 6 ♀<br>8 ♂*, 10 ♀* | Ninety-microgram estradiol benzoate pellet implanted into right femur | 3 or 4 |
| Group V-A | 2 ♂, 2 ♀ | Both femora drilled; ninety-microgram estradiol benzoate pellet implanted in right femur only | 4 |
| Group VI | 3 ♂, 2 ♀<br>1 ♂*, 2 ♀* | Two-milligram testosterone propionate pellet implanted into right femur | 1 or 2 |
| | 7 ♂, 6 ♀<br>3 ♂*, 3 ♀* | Two-milligram testosterone propionate pellet implanted into right femur | 3 or 4 |
| Group VII | 2 ♂, 2 ♀<br>2 ♂*, 2 ♀* | Eighty-microgram testosterone propionate pellet implanted into right femur; ninety-microgram estradiol benzoate pellet implanted subcutaneously | 1 or 2 |
| | 3 ♂, 4 ♀<br>5 ♂*, 4 ♀* | Two-milligram testosterone propionate pellet implanted into right femur; ninety-microgram estradiol benzoate pellet implanted subcutaneously | 1 or 2 |
| | 2 ♂, 2 ♀<br>2 ♂*, 2 ♀* | Eighty-microgram testosterone propionate pellet implanted into right femur; ninety-microgram estradiol benzoate pellet implanted subcutaneously | 3 or 4 |
| | 4 ♂, 2 ♀<br>3 ♂*, 4 ♀* | Two-milligram testosterone propionate pellet implanted into right femur; ninety-microgram estradiol benzoate pellet implanted subcutaneously | 3 or 4 |

* Castrated animals.

cavities and pellets containing ninety micrograms of estradiol benzoate subcutaneously, the following changes occurred (Fig. 8):

*One to two weeks:* The distal metaphyses of the implanted femora had a number of thin spicules of bone which did not coalesce with the sealing callus. Small amounts of bridging, anchoring, and uniting callus were present around and in the drilled sites. Sealing callus was continuous with the lateral endosteal part of the compact bone, while anteriorly and posteriorly the marrow cavities proximal and distal to the lesions were continuous and filled with red marrow. The parts of the bones proximal to the drilled sites were normal. In the contralateral femora, metaphyses were similar to the drilled femora in this group, with no noticeable changes in the proximal four-fifths of the femora.

*Three to four weeks:* The trabeculae of the distal metaphyses and the drilled sites coalesced without becoming continuous (Figs. 9-A, 9-B, and 9-C). Bone trabeculae were more numerous than during the one-to-two-week period, but no changes took place on the proximal portions of the femora. The metaphyses in the contralateral femora were similar to the drilled femora, but hyperostoses were less than in homologous femora of estradiol benzoate implanted groups (Figs. 10-A and 10-B). The proximal three-fourths of the femora was unaffected.

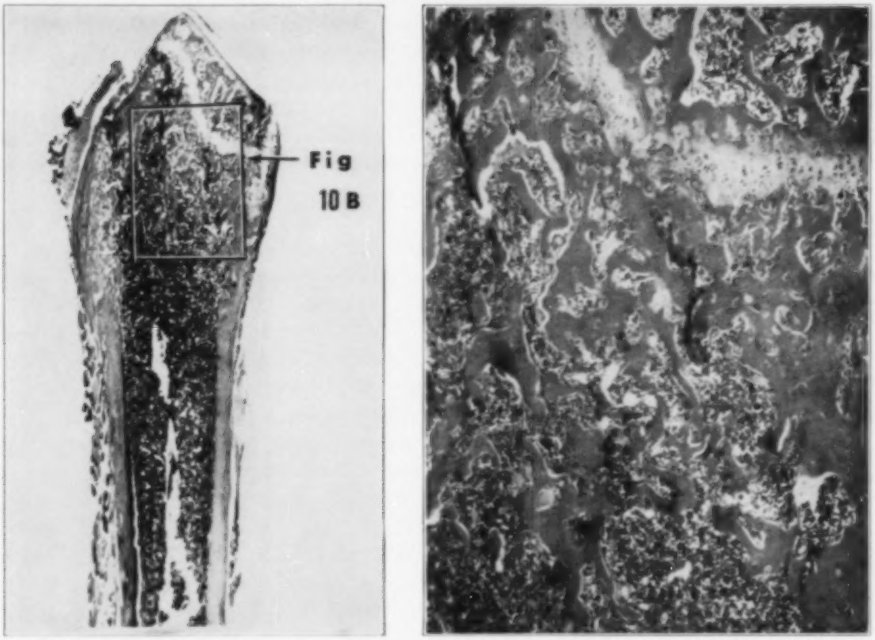

Fig. 10-A

Fig. 10-B

Fig. 10-A: Distal half of the contralateral femur from the same mouse as in Fig. 9-A. The distal metaphysis had trabecular proliferations equal to the treated femora (× 22).

Fig. 10-B: Distal metaphyseal-epiphyseal junction of the same femur as in Fig. 10-A. (Note the similarity with Fig. 9-B.) This indicated that an intrafemorally implanted testosterone propionate pellet inhibited estradiol-benzoate-induced endosteal-bone formation in the untreated contralateral femur (× 67).

## DISCUSSION

A number of factors enter into the reaction of steroids on bones, such as the effects of age, sex, strain, and species differences. These have been adequately reviewed by Silberberg and Silberberg. Within the mammalian class, mice are suitable for study since they seem to have the greatest response to steroids.

At autopsy, the uteri were hypertrophied and distended with fluid. Estrogenic pellets containing ninety micrograms of estradiol benzoate were present at necropsy. Although it is quite probable that not all of the hormone was absorbed, exactly how much was metabolized and in what form is not known. The fact that the hormone was being released continuously during the experimental period made it unphysiological, and from that viewpoint the amount was high. On the other hand, Urist and associates gave a total of two milligrams of estradiol benzoate to mice in different liquid vehicles for a comparable period of time. This was a minimum of twenty times more than the amount given to mice in the present experiments. The dosages of testosterone propionate can be considered small since as much as 2.5 milligrams weekly have been given to mice[7].

Implantations of testosterone propionate and cholesterol did not induce any endosteal-bone formation either in the metaphyses or drilled sites of the femora. The few spicules of bone that developed in the marrow under the drilled site were due to traumatic responses to the lesion, since untreated drilled femora had only a few spicules of osseous tissue under the lesion. These results are in concord with those of Benoit and Clavert, who implanted testosterone propionate crystals in duck and pigeon tibiae.

After implanting mice with estradiol benzoate pellets, osteoblasts in the region of the drilled sites were stimulated to form osseous callus. This occurred whether the estradiol benzoate pellets were administered subcutaneously or intrafemorally, and confirmed the results of Pollock, and Pollock and Ghormley, who suggested that estrogens stimulated the formation of osseous callus after experimental fracturing of rat humeri. In the present experiments, trauma also induced greater endosteal ossification at the distal metaphyses of both the traumatized and contralateral femora than if the same amount of estradiol benzoate were administered without making lesions in the femora[15]. A possible explanation of this finding may be that an endogenous bone proliferating stimulant is produced as a result of the trauma which enhanced the systemic endosteal ossification induced by the estradiol benzoate. In addition, topical applications of estrone crystals (one to two milligrams) under the patellar ligaments of mice induced localized growths of bone as well as growths in the contralateral femora[3]. On the other hand, other investigators[1,2,10] concluded that estrogens induced only local calcification in treated duck and mouse bones. In their experiments, estrogenic pellets were implanted into the marrow cavities of bone, thus producing osteogenic responses to the trauma. In the present experiments, after a lesion was made into the femur and estradiol benzoate pellets implanted subcutaneously, osseous callus and distal metaphyseal proliferations of trabeculae were similar to those in femora intrafemorally implanted with estradiol benzoate. Therefore, one cannot interpret the observations of the previous investigators[1,2,10] as a result of local implantation of estrogen *per se*.

Since no inhibition of estradiol-induced endosteal-bone formation occurred when eighty micrograms of testosterone propionate was implanted locally, simultaneously with subcutaneous estradiol benzoate pellets, a question arose whether or not testosterone propionate, when given in small amounts, augmented calcification. This was tested on mice who had intrafemoral cholesterol in addition to subcutaneous estradiol benzoate pellets. This group had bone proliferation comparable in amount to that in the group implanted with eighty micrograms of testosterone propionate as well as ninety micrograms of estradiol benzoate. Thus, estrogens alone greatly induced bone formation after trauma.

After systemically injecting mice with testosterone propionate (up to 2.5 milligrams weekly) and estrogens (eight to 150 micrograms weekly) for long periods of time, complete inhibition of estrogenic-induced bone formation took place. This was determined quantitatively by ash weights[5,9,10,18], and qualitatively through microscopic examinations[7]. In the present experiments, almost complete inhibition of systemically-induced estradiol benzoate callus formation and distal metaphyseal proliferations took place in the operated femora. Likewise, testosterone propionate implanted in the right femora inhibited bone formation in the contralateral femora. These experiments indicated that enough androgen from intra-osseous implantations gets into the circulatory system to inhibit endosteal ossification in the contralateral femora and to give results comparable to those obtained when both androgens and estrogens were injected systematically[5,7,9,10,18].

## SUMMARY

1. One hundred and sixty-seven mice had cavities drilled into their right femora and were divided into seven groups with or without intrafemoral placement of hormones or placebos.

2. Mice which had cavities drilled only into their femora or had cholesterol placebos or testosterone propionate pellets implanted intrafemorally showed little endosteal bone proliferation in the distal metaphyses and callus formation at the drilled sites four weeks after implantation.

3. Both intrafemoral and systemic applications of ninety micrograms of estradiol-benzoate induced localized hyperostosis in the traumatized regions. However, four weeks after hormone implantation the distal metaphyses of both femora were endosteally proliferated to approximately the same degree, due to the systemic effects of estradiol benzoate.

4. Over eighty micrograms of intrafemorally placed testosterone propionate was needed to inhibit the effects produced by ninety-microgram pellets of estradiol benzoate placed subcutaneously. However, the androgen inhibited the estrogenic activity not only in the drilled femur, but also in the contralateral one.

5. No sexual differences were observed in response to the dosages of hormones given. Differences in femoral changes between castrated and non-castrated mice were not seen.

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# Repair of Bone-Transplant Fractures*†

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The recent increased use of preserved homogenous bone has been accompanied by the revival of an old controversy to determine which type of bone transplant is superior. The majority of investigators concluded that fresh autogenous bone is superior to other types of transplants such as fresh homogenous bone, frozen homogenous bone, freeze-dried, and merthiolate-stored homogenous bone. However, many investigators believed the difference in results is not sufficiently significant to warrant the additional risk to the patient, or additional expenditure of time by the surgeon to obtain the fresh autogenous transplant. The advocates of this latter idea support the use of bone-bank bone either frozen, freeze-dried, or preserved in merthiolate. Recent experimental and clinical studies by Wilson, Garber and Bush, Reynolds and Oliver, and Kreuz and associates have led to the opinion that the healing of bone-bank bone, although somewhat slower to repair in the earlier stages than fresh autogenous bone, was eventually as good or better than fresh autogenous bone. These investigators maintained that all transplanted bone dies, and that the host connective tissue alone is responsible for invasion and replacement of the graft as a scaffold.

In an attempt to evaluate the problem, experiments were undertaken in rabbits to study the repair of fractures in bone transplants of various types. Fresh, frozen, and boiled autogenous transplants, and fresh, frozen, freeze-dried, and merthiolate-preserved homogenous transplants were studied. Graft fracture healing was used as a criterion of the repair capacity of the transplant since host bone callus would be less likely to influence that site. Graft fracture healing would then depend on the type of transplant, the response of the osteogenic cells of the fractured bone, and the response of the host connective tissue to the graft.

Throughout the literature on bone transplantation there is reference to the relation of tissue specificity to homogenous-bone grafts. In addition to the histological approach of evaluating the various types of bone transplants, the immunological response of the various transplants was studied [2].

The fresh and frozen homogenous transplants induced a cellular inflammatory reaction similar to that described for other homogenous-graft tissues. The collections of inflammatory cells are primarily round cells such as lymphocytes, monocytes, macrophages (histiocytes), and scattered eosinophils. In addition, vascular fibrous tissue intervened between the end of the homogenous-bone graft and the host bone callus, suggesting rejection by the host of the transplant.

A comparison of the reactions to fresh and frozen homogenous grafts revealed that the reactions were most intense from two to four weeks in fresh homogenous grafts and although less intense initially, persisted up to twelve to eighteen weeks in frozen homogenous grafts. Comparison of the inflammatory reaction to primary and secondary homogenous grafts demonstrated an increase and persistence of the reaction to secondary homogenous grafts after three weeks. The findings are consistent with a host incompatibility and a rejection reaction to homogenous-bone grafts.

A method for the extraction of soluble proteins from whole bone has been developed.

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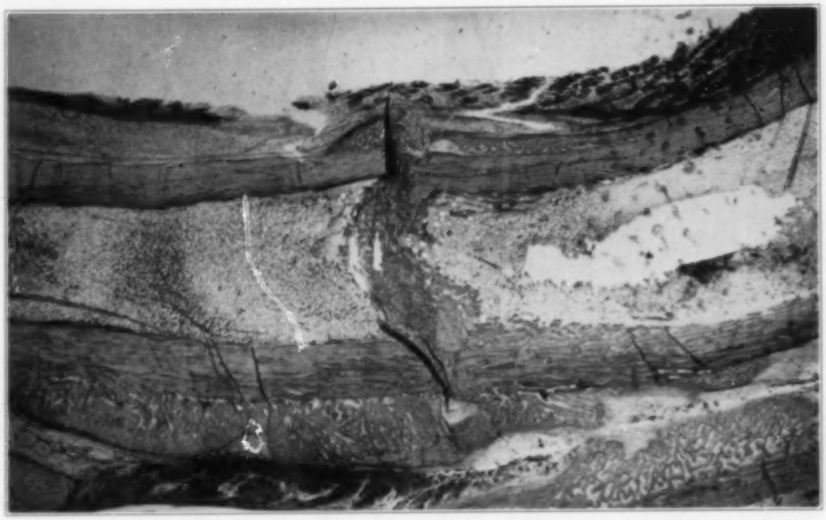

FIG. 1

Two-week fresh autogenous transplant fracture with bone union by intramedullary and periosteal callus (× 9).

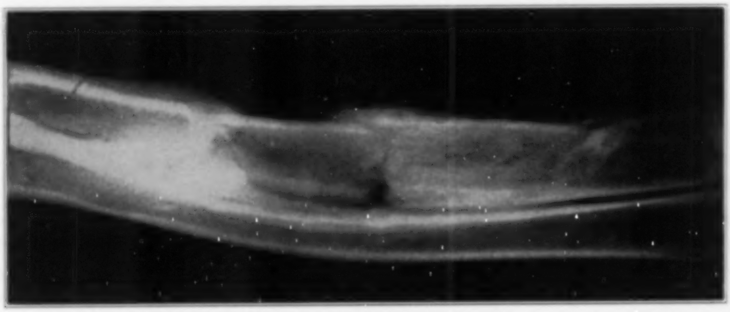

FIG. 2

Roentgenogram of the total specimen of a four-week fresh autogenous transplant.

Sera from animals grafted without immunization show no demonstrable antibodies. However, animals immunized with extracts and adjuvants produced antibodies of low titer demonstrable by complement fixation reactions. These antibodies appeared to obey the laws of the specific antibody response. The immunization procedure resulted in a markedly diminished inflammatory response around a graft placed in the immunized animal. Primary grafting does not protect a second homogenous graft but actually increases the inflammatory reaction.

## METHOD

Large young adult male rabbits were used. Three-centimeter segments of bone with periosteum intact were removed from the right ulna, fractured at mid-point, and replaced in the same defect for autogenous fresh grafts (Fig. 2). Fresh homogenous transplantations were accomplished by direct transfer of ulnar segments from pairs of rabbits. Frozen grafts were stored in sterile double-glass containers at −15 to −20 degrees centigrade for periods of from one to twelve weeks before use. Freeze-dried grafts were sealed under vacuum in glass tubes and stored at room temperature. At the time of operation the freeze-

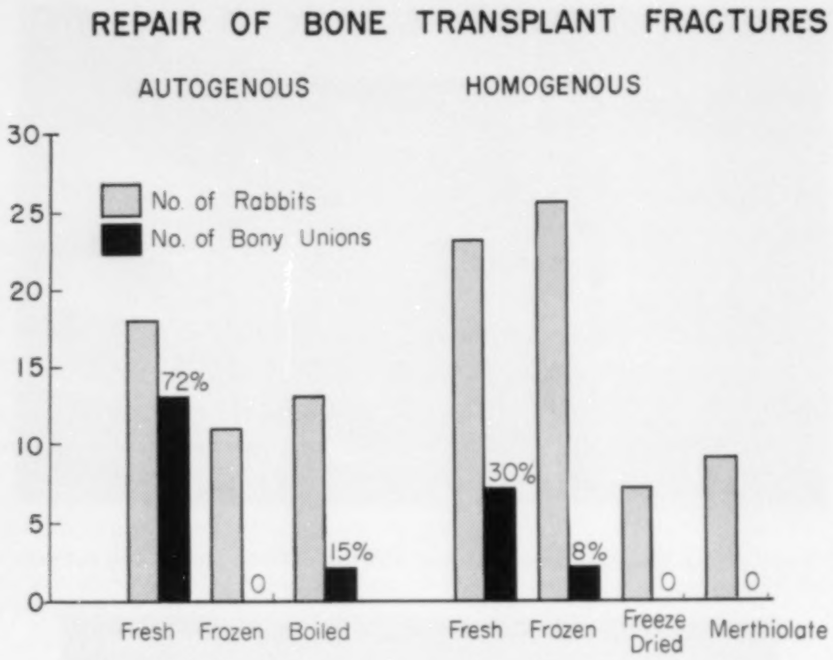

CHART I

dried grafts were placed in a normal saline solution before they were fractured and placed in the rabbits. Bone segments were stored in 1:1000 solution of merthiolate at least one week before use. The forelimb was immobilized in a light plaster dressing. Groups of six animals each in the fresh autogenous and frozen homogenous series were sacrificed at intervals of from one to five, twelve, or eighteen weeks. The other series were terminated at twelve weeks. One hundred and seven rabbits are included in the final study. Roentgenograms were made of each specimen at the time of sacrifice and the evidence of union or non-union was recorded. Since the histological preparation in each instance agreed with the roentgenographic findings, the results were based on the histological evidence of osseous bridging between transplant fracture fragments. Where fibrous tissue or fibrocartilage intervened between the transplant fragments, the instance was cited as non-union for the purpose of this study. Celloidin sections were prepared for histological study.

## RESULTS

Chart I summarizes the results of graft fracture healing.

### *Fresh Autogenous Transplants*

In thirteen of eighteen rabbits, fresh autogenous graft fractures united solidly with bone as early as two weeks (Fig. 1). The appearance of the fracture repair is similar to that of the repair of an ordinary fracture in a rabbit. Both periosteal and intramedullary osseous callus were present. The roentgenogram and microscopic section of a four-week-old graft demonstrated bone union at the graft host sites as well as at the graft fracture site (Fig. 2). Three of the graft fractures had cartilaginous and osseous callus and only two had fibrous union. In one of these at five weeks, non-union was due to displacement of fragments. Abundant bone and cartilaginous callus was seen arising from the fragments (Fig. 3).

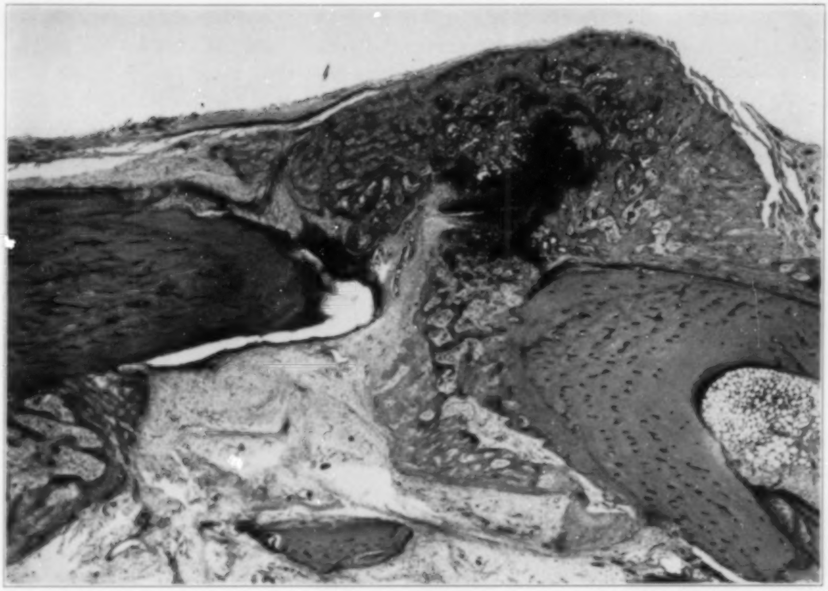

FIG. 3

Abundant cartilaginous and bone callus occurred at a five-week fresh autogenous transplant fracture site. Non-union as a result of displacement of the graft fragments is shown (× 15.5).

At nine weeks, the graft cortices were united by mature periosteal and endosteal bone. In addition, moderate replacement of the transplant by living bone had occurred (Fig. 4). The characteristic features of autogenous-bone repair so well described by Axhausen, Phemister, and most recently by Campbell and associates were observed in the fresh autogenous grafts and need not be repeated here.

*Frozen Autogenous Transplants*

None of the fractures in this group of eleven rabbits united. Little or no osteogenic

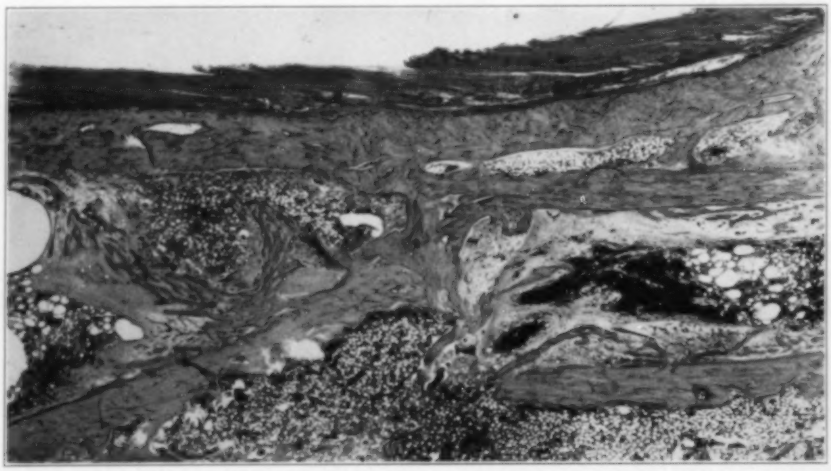

FIG. 4

Nine-week fresh autogenous graft with osseous union. Endosteal and periosteal new bone and moderate graft cortex replacement is shown (× 11).

stimulus was observed at the fracture site. The grafts were completely necrotic and underwent very gradual resorption and replacement by new bone so that by the end of five weeks about 5 per cent was replaced. By the end of twelve weeks, only 30 per cent was replaced. No inflammatory reaction was noted about any of these.

### *Boiled Autogenous Transplants*

Although two of the thirteen fractures united (at six and twelve weeks), the replacement of boiled bone by new bone was minimal as compared with autogenous-bone repair at corresponding time intervals.

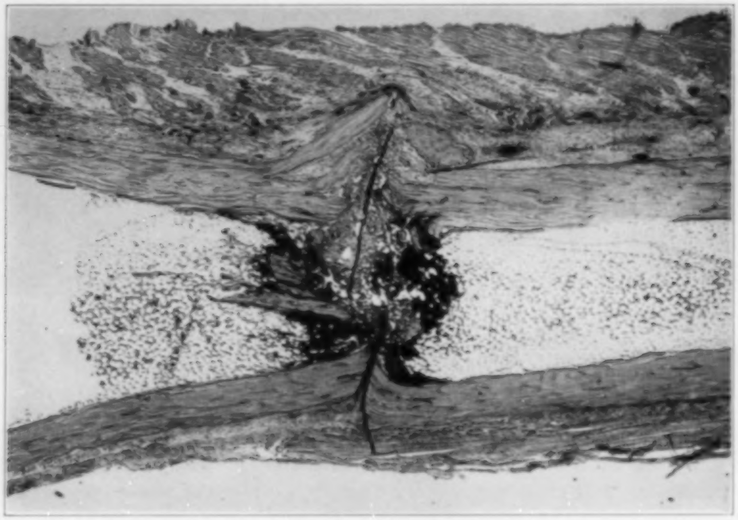

Fig. 5

Two-week fresh homogenous transplant with marked round-cell infiltration at the fracture site. Note absence of periosteal and medullary new bone (× 4). (Reprinted by permission from "Repair of Bone Transplant Fractures" by Michael Bonfiglio, *Surgical Forum*, Vol. VI, p. 531. Chicago, American College of Surgeons, 1956.)

### *Fresh Homogenous Transplants*

Seven of twenty-three animals in this group had bone union of the transplant fracture. The earliest occurred in an animal sacrificed at four weeks. In the first few weeks, the fracture site showed invasion of host granulation tissue with marked round-cell infiltration (Fig. 5). The granulation tissue changed to fibrocartilage, cartilage, and bone in those instances when union occurred at four weeks or later (Fig. 6). The fracture sites in the other animals in this group were fibrous or fibrocartilaginous.

At the end of twelve weeks the animals with non-union demonstrated mature, less cellular fibrous tissue at the fracture site with absorption of adjacent cortical bone (Fig. 7). The homogenous bone graft replacement occurred first by vascular connective-tissue invasion, bone absorption, and later by ossification of the fibrous tissue. The more direct resorption and reapposition of new bone usually seen in autogenous grafts was less evident in the homogenous bone.

In addition, as previously reported, a cellular inflammatory reaction occurred between the graft and the overlying muscle. This was most intense at three weeks and gradually subsided but did not completely disappear as long as unreplaced homogenous bone remained. This appears to be an immunological response[2].

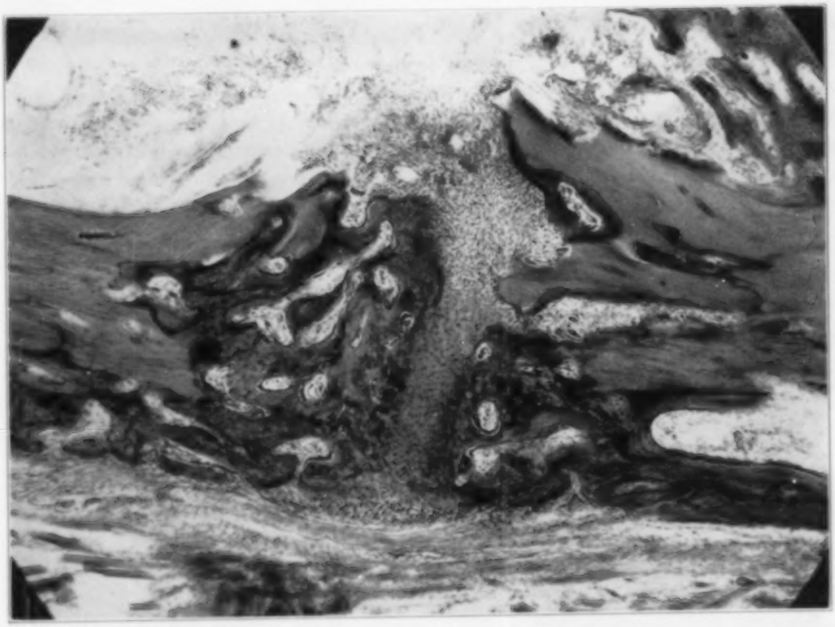

Fig. 6

Five-week fresh homogenous graft fracture with cartilaginous and bone union of one cortex (× 55).

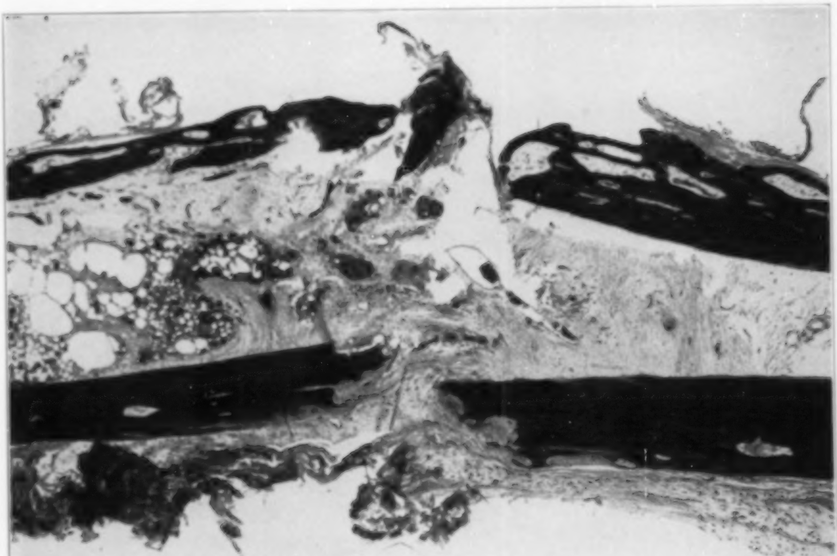

Fig. 7

A twelve-week fresh homogenous implant with fibrous non-union at the fracture site and marginal absorption of bone (× 11).

*Frozen Homogenous Transplants*

Bone union resulted in only two of twenty-six rabbits. One fracture united at six weeks; the other in eighteen weeks. The remaining fractures united by fibrous tissue only. The usual type of fracture repair was conspicuous by its absence. Frozen homogenous grafts displayed a lack of osteogenic stimulus to the mesenchymal cells of the surrounding connective tissue. The absorptive reaction present in fresh homogenous grafts was less

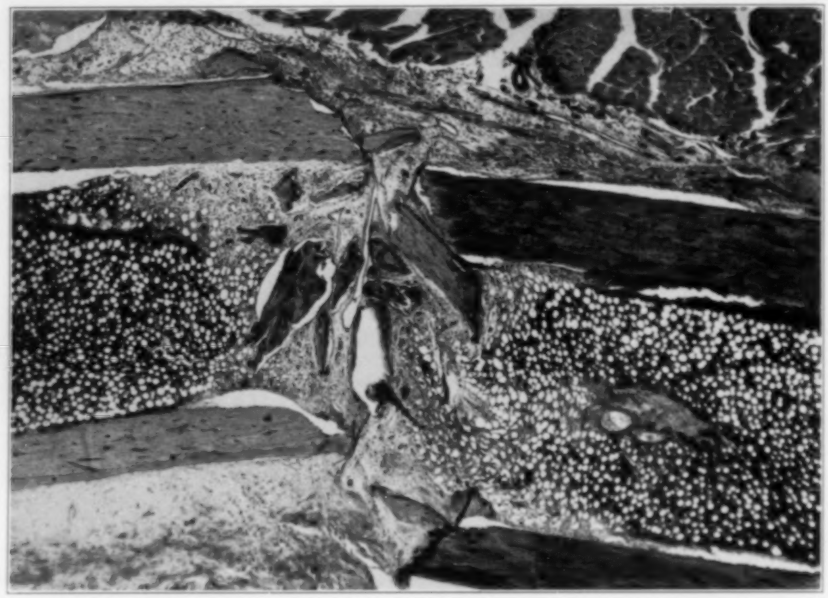

FIG. 8

Three-week frozen homogenous bone with fibrous tissue at the fracture site (× 15.5).

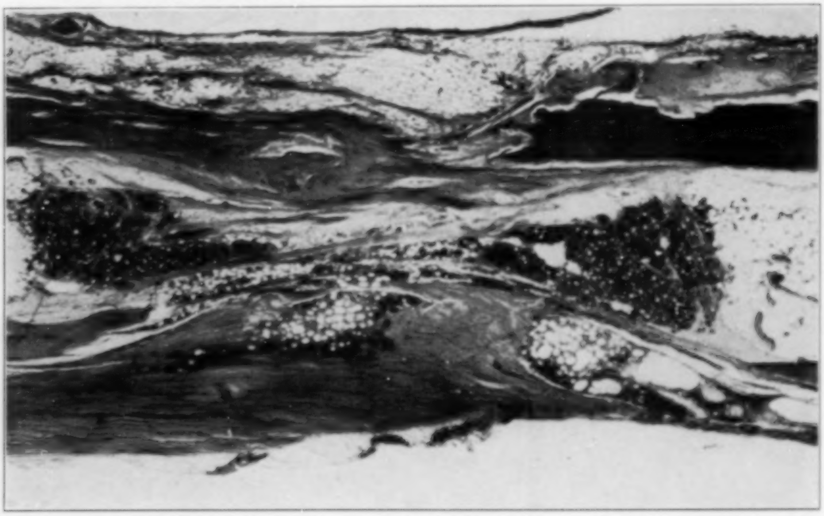

FIG. 9

Eighteen-week frozen homogenous graft with fibrous union at the fracture site, thinning, and marginal absorption of bone (× 8.5).

evident, particularly in the early weeks as shown in a three-week implant (Fig. 8).

The frozen homogenous bone segments underwent gradual fibrous-tissue absorption with minimal new-bone replacement of the cortex. The graft fracture site had widened in an eighteen-week animal (Fig. 9). Cellular inflammatory reaction to the frozen homogenous grafts was less intense than in fresh homogenous grafts.

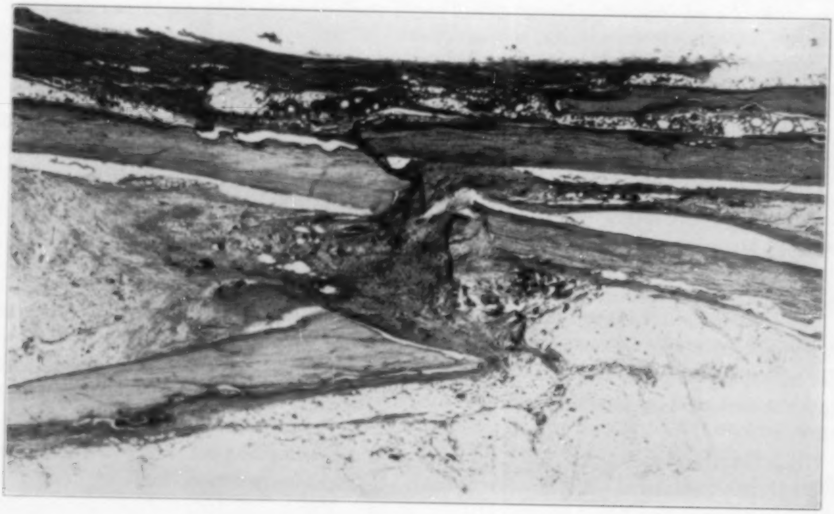

FIG. 10

Twelve-week, freeze-dried homogenous graft with non-union at the fracture site and marginal absorption of bone (× 8).

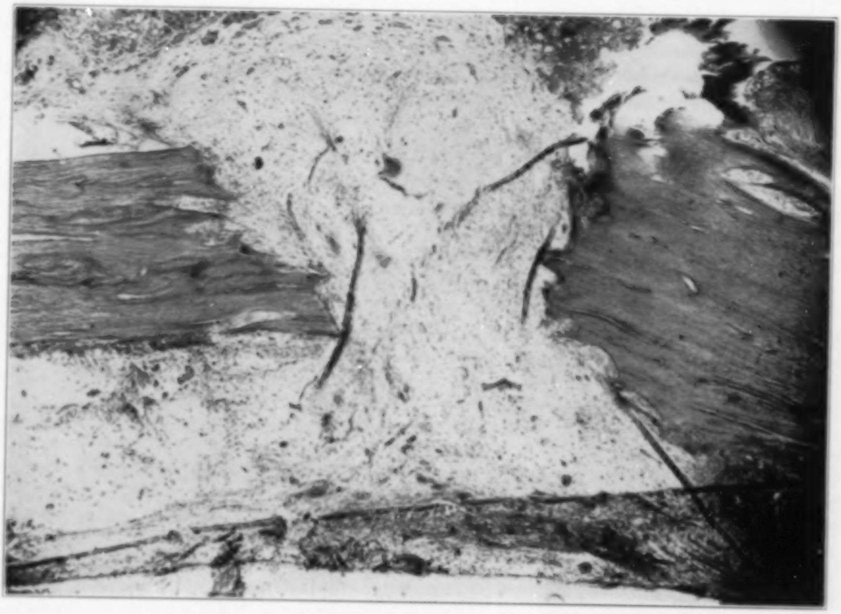

FIG. 11

Twelve-week merthiolate-stored homogenous bone with non-union and lacunar absorption of the fragment ends (× 52).

### *Freeze-Dried Homogenous Transplants*

Fibrous non-union occurred in seven animals sacrificed from two to twelve weeks. No attempt at fibrocartilage, cartilage, or bone formation at the fracture site could be noted in a twelve-week implant. Cortical repair was similar to that observed for frozen homogenous grafts. The cellular inflammatory reaction was minimal. A low-power photomicrograph of a twelve-week freeze-dried implant illustrates these findings (Fig. 10).

### *Merthiolate-Preserved Homogenous Transplants*

In two of the nine rabbits in this group, partial bone and cartilaginous union occurred at twelve weeks. Otherwise, the bone repair and reaction were similar to those of freeze-dried and frozen homogenous grafts.

Figure 11 demonstrates a loose connective tissue between the fracture ends of a twelve-week merthiolate-preserved implant. There is marginal absorption of the bone and absence of creeping substitution.

## SUMMARY AND CONCLUSIONS

Fresh autogenous-bone transplant fractures in rabbits have the capacity to unite as early as two weeks in more than two-thirds of the animals. Some of the surface cells of the transplants appeared to survive and proliferate to produce new bone. The graft replacement occurred by creeping substitution. The transplants were well tolerated by host tissues.

Graft fracture healing in fresh homogenous transplants was delayed by several weeks, and less than one-third of the fractures united. Marked absorption of the fresh homogenous implant predominated prior to ossification, if any. Fresh and frozen homogenous transplants induced a cellular inflammatory reaction similar to that described for other homogenous graft tissue. Frozen, freeze-dried, and merthiolate-preserved homogenous-bone implants produced little osteogenic stimulus in the host tissues. Graft fractures usually do not unite. These grafts were replaced very slowly, if at all, by fibrous tissue first, and then by bone.

Fresh autogenous-bone transplants are far superior to any other type of bone transplant. The repair capacity of fresh autogenous grafts as measured by graft fracture healing exceeds that of fresh, frozen, freeze-dried, merthiolate-preserved homogenous grafts, or frozen and boiled autogenous grafts. Fresh homogenous grafts exhibited the next best osteogenic-repair capacity; however, the marked inflammatory incompatibility reaction to the homogenous bone may be detrimental.

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## DISCUSSION

Dr. Crawford J. Campbell, Albany, New York: In this paper Dr. Bonfiglio has added further evidence to indicate that the osteogenic capacity of fresh autogenous bone is superior to that of fresh or preserved homogenous-bone transplants. Most bone-graft experiments have been done on implants placed in a cavity or defect within a bone[a]. Interpretation of such results may be difficult because of the marked osteogenic response from the host tissue. Dr. Bonfiglio has avoided this pitfall by resecting segments of the central portion of a long bone and filling this defect with a segment of cortical bone which he fractured in the mid-portion. The healing of such a fracture in this location is certainly the supreme test for any grafting procedure.

Some investigators may argue that even though some osteogenic cells of grafts survive, this is not significant from a clinical point of view. From our previous work on cortical and cancellous bone grafts[b], and from our clinical experience, we believe that the osteogenic capacity of fresh autogenous cancellous-bone grafts is significant.

a. Barth, Arthur: Ueber histologische Befunde nach Knochenimplantationen. Arch. f. Klin. Chir., **46:** 409–417, 1893.

b. Campbell, C. J.; Brower, T.; MacFadden, D. G.; Payne, E. B.; and Doherty, J.: Experimental Study of the Fate of Bone Grafts. J. Bone and Joint Surg., **35-A:** 332–346, Apr. 1953.

Cmdr. George W. Hyatt, Bethesda, Maryland: The author has presented a method of biological investigation of the reparative capacity of a graft which is not only ingenious but clearly demonstrates the marked ability of an autogenous graft, fractured in its middle, to heal when placed in its original site in the rabbit. However, rabbits are noted not only for their ability to form bone, but also for their ability, along with horses, to produce antibodies.

Before we scrutinize methodology, certain fundamentals should be emphasized. Somewhere in this controversy, there is a mid-point between those who stoutly maintain that bone-bank bone is better than fresh autogenous bone and those who believe in autogenous bone grafts. The following are presented for consideration:

Mid-point 1: The autogenous graft was, is, and will remain the ideal transplant when it is appropriately and humanely available.

Mid-point 2: The stored homogenous graft is a second-rate graft; it may be, however, the graft of choice in selected cases.

Mid-point 3: The homogenous-graft cells of adult bone do not survive transplantation even if local nutrition permitted survival because of the general homogenous-graft response. This response results in cell death of appropriately vascularized tissue of the homogenous grafts in general.

In all transplants, according to the paper, periosteum was maintained intact and replaced in the test defect. In a crude way this autogenous-graft-test concept resembles open reduction of an extensively comminuted fracture. As the clot is a primary nutrient at first, it may maintain viability of the graft by diffusion. The cell physiologists have evaluated many tissue explants and have noted over the years that a piece of tissue, devoid of blood supply and of low matrix density will undergo necrosis when the explant is larger than one millimeter in depth and one millimeter in width.

It is expected then that a three-centimeter whole-shaft transplant, with periosteum intact, will be nourished for a depth which approximates one millimeter. By replacing the graft in its original anatomical site, we cannot exclude vascular orientation between host and graft, which is a most unlikely clinical probability. With diffusion nutrient probable for only one millimeter of the graft substance, the indications for significant survival of autogenous-bone-graft cells in relation to total bone cells available for survival is quite small.

It is important, too, to emphasize that in this method we do not deal with bone alone, but with periosteum also. We may reasonably expect survival of the periosteum and its attached soft-tissue cells. This, in addition to the characteristic biochemistry of the fracture clot, the placement of the graft into a physiological stress pattern, and the fact that the vascular supply was normal in the beginning, gives the essentials for healing of a comminuted fracture.

The survival of superficial autogenous-graft cells and their own capacity for evoking reactive bone formation is quite interesting. The author is to be congratulated, for this is an *in vivo* tissue culture of bone in a spectacular manner and on a grand scale. Unfortunately, this technique, as currently accomplished, does not permit differentiation of graft cells from host cells so that we cannot evaluate qualitative survival, let alone validated quantitative data. It is extremely important to emphasize that if the periosteum were not intact in the homogenous graft, the conclusions are invalid immediately.

On the presumption that the periosteum is intact, it is again noted that adult homogenous-graft cells not only of bone but also of the vast majority of tissue do not survive when vascularized. They participate in the homogenous-graft response, die, and form scar as do other dead cells. When we freeze, boil, or freeze-dry this test object, we leave a periosteum around the graft that leaves a nice collagenous, although dead, sheath. The vascular buds of the host then must penetrate this before they can even begin to revascularize the graft.

I should like to know the criteria for Dr. Bonfiglio's freeze-dried bone. These were established at the Academy over a year ago. Briefly what measures were taken to prevent the bone from thawing during the freeze-dry cycle? What were the residual moistures of this finally transplanted graft? However, the truly interesting observations are the relatively high level of healing of the fresh homogenous grafts and the amazing observations that boiled bone healed at all.

To conclude and to take the same heavy-handed liberty with clinical implications that the author has taken, this experimental method roughly compares to the healing expected from the comminuted fracture involving the shaft of a long bone treated by open reduction. In contrast, healing expected from a free bone graft must span about one-half of the shaft length.

**Dr. Bonfiglio** (closing): I wish to thank both discussors for their very kind remarks. I would like to clarify one or two points for Dr. Hyatt concerning the periosteum. You asked whether the periosteum was left on the homogenous preparations as well as on the autogenous graft—it was. The experimental conditions were the same for all of the tissues used. It is true that periosteum will survive and produce new bone. This is a very important part of the repair of autogenous grafts. It is also true that the majority of bone cells in autogenous grafts die and are replaced by the usual host tissue substitution.

If you remove a large segment of bone which constitutes at least half of the long bone involved, the blood supply of that area has no direct relationship to the segment of bone that was removed. The question of orientation of blood vessels in one direction or another presumes the idea that the blood supply is reestablished so quickly that the whole thing can remain alive. This idea is preposterous. It can't do that. Even if you reverse the bone from one direction to the other, which was done, it would not alter the experimental findings. The interpretation that this is applied on a clinical basis is made by Dr. Hyatt himself, and was not implied. As stated at the beginning of this paper, this was an experimental project which employed the rabbit as an experimental animal and obviously pertains to rabbits.

# Sulphur Metabolism in Cartilage

## I. JOINT-FLUID SULPHATE *

BY O. DONALD CHRISMAN, M.D., CHARLES O. BECHTOL, M.D., ROSE R. COELHO, PH.D.,
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*From the Department of Orthopaedic Surgery, School of Medicine, Yale University, New Haven and the Cooley-Dickinson Hospital, Northampton, Massachusetts*

### INTRODUCTION

It is generally considered that synovial fluid is a dialysate in equilibrium with blood plasma. Except for the protein constituents, including mucin, the distribution of electrolytes and non-electrolytes in joint fluid in health and in disease is, in the main, consistent with the values predictable by the Gibbs-Donnan theory of membrane equilibrium [2]. The origin of mucin, whether from cartilage or synovial membrane, has been a matter of considerable debate, with most of the evidence favoring a synovial source [5,7,10,11,16]. There has been very little evidence that cartilage breakdown adds much to the synovial fluid, although loose bodies and débris are found, especially in the synovium of joints severely eroded from trauma or neurogenic arthropathy [3,9]. According to Davies it is extremely difficult to find any products of cartilage erosion in synovial fluid [1].

TABLE I

INORGANIC SULPHATE CONCENTRATION IN TRAUMATIC DEGENERATIVE ARTHRITIS OF OVER THREE MONTHS' DURATION

| No. | Age | Serum (*Milligrams per 100 Milliliters*) | Synovial Fluid (*Milligrams per 100 Milliliters*) | Difference |
|---|---|---|---|---|
| 1 | 60 | 0.95 | 1.25 | + .31 |
| 2 | 65 | 1.39 | 1.50 | + .11 |
| 3 | 62 | 1.12 | 1.56 | + .44 |
| 4 | 70 | 0.93 | 1.09 | + .16 |
| 5 | 85 | 1.26 | 1.58 | + .32 |
| 6 | 72 | 1.56 | 2.03 | + .47 |
| 7 | 64 | 1.06 | 1.22 | + .16 |
| 8 | 34 | 1.38 | 2.45 | +1.07 |
| 9 | 78 | 1.25 | 1.40 | + .15 |
| 10 | 47 | 0.42 | 0.41 | − .01 |
| 11 | 45 | 0.92 | 1.55 | + .63 |
| 12 | 70 | 0.31 | 0.51 | + .20 |
| 13 | 77 | 0.80 | 1.54 | + .74 |

Mean difference = 0.365
S.E. = 0.265
The probability that the observed difference would be found if in fact there were no true difference $< 0.001$.

However, in traumatic arthritis of various types, areas of cartilage lose their clear color and firm elasticity, and fissures and sections of fragmentation occur [8,13,17]. The loss of metachromatic ground substances has been proved by staining and chemical methods [4,8,13]. It is the purpose of this paper to compare the joint-fluid sulphate with the serum sulphate in various types of arthritis in order to see if there is chemical evidence present of cartilage degeneration. Previous measurements of joint-fluid sulphate have been done only for relatively normal bovine joint fluid[14] and gave an average sulphate value of 4.96 milliequivalents per liter in joint fluid as compared with 5.56 milliequivalents per liter in serum, about a 7 per cent downward deviation from the theoretical Donnan expectation. This deviation was considered by the authors to be the result of inaccuracy of the method rather than a true difference. No pathological fluids were tested.

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* Read at the Annual Meeting of the Orthopaedic Research Society, Chicago, Illinois, January 25, 1957.

## METHOD

The knee was the usual joint from which fluid was taken, although the ankle and hip joints were occasionally used. Usual aspiration technique was employed with novocain or xylocaine anaesthesia for the skin but not the deeper tissues in order to avoid contamination of the fluid. Two cubic centimeters or more of joint fluid was removed and, at the same time, ten cubic centimeters of clotted blood was obtained from an antecubital vein. Some of the patients were fasting and some were not; there was no clear distinction in the results on this basis. Hemolyzed samples were necessarily rejected because of the higher sulphate values after red-cell disintegration. The sulphate was then determined by a benzidine method[12] with test accuracy allowing an error of about 5 per cent. The suspension was allowed to sit overnight at 6 degrees centigrade instead of two hours.

TABLE II

INORGANIC SULPHATE CONCENTRATION

| No. | Age | Serum (*Milligrams per 100 Milliliters*) | Synovial Fluid (*Milligrams per 100 Milliliters*) | Difference |
|---|---|---|---|---|
| Osteochondritis dissecans | | | | |
| 14 | 16 | 1.51 | 1.62 | + .11 |
| 15 | 19 | 1.00 | 1.13 | + .13 |
| Charcot's joint | | | | |
| 16 | 75 | 1.36 | 1.40 | + .04 |
| Rheumatoid arthritis | | | | |
| 17 | 9 | 1.40 | 0.90 | − .50 |
| 18 | 40 | 0.94 | 0.99 | + .05 |
| 19 | 80 | 0.94 | 0.34 | − .60 |
| 20 | 25 | 1.63 | 1.18 | − .45 |
| 21 | 30 | 1.12 | 0.93 | − .19 |
| 22 | 81 | 1.29 lt. | 1.23 | − .06 |
| 22 | 81 | 1.29 rt. | 1.22 | − .07 |

Mean difference = − 0.26 in rheumatoid arthritis
S.E. = 0.302
P. $< 0.001$

## RESULTS

Consecutive patients were tapped and tested for an eighteen-month period, the only samples discarded being the hemolyzed ones. The diagnosis of the type of arthritis present was checked by physicians when the clinical picture was unusual. The results were then arranged by diagnosis as carefully as possible, the criteria of Ropes and Bauer being used. Results in recent acute synovitis of less than three months' duration were separated from those in more advanced traumatic degenerative arthritis of Group I. Group II rheumatoid arthritic patients also were subjected to statistical analysis *. The difference between the

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* Performed by Dr. Colin White of the Medical Statistics Department, Yale University School of Medicine.

TABLE III

Inorganic Sulphate Concentration in Recent Acute Traumatic Synovitis of Less than Three Months' Duration
(Ropes and Bauer 1953)

| No. | Age | Serum (*Milligrams per 100 Milliliters*) | Synovial Fluid (*Milligrams per 100 Milliliters*) | Difference |
|---|---|---|---|---|
| 23 | 39 | 1.14 | 1.12 | − .02 |
| 24 | 42 | 1.06 | 1.10 | + .04 |
| 25 | 60 | 0.96 | 0.97 | + .01 |
| 26 | 56 | 1.54 | 1.25 | − .29 |
| 27 | 48 | 1.43 | 1.46 | + .03 |
| 28 | 31 | 1.22 | 1.22 | .00 |
| 29 | 45 | 1.09 | 0.73 | − .36 |
| 30 | 22 | 1.10 | 1.04 | − .06 |
| 31 | 21 | 1.00 | 1.00 | .00 |
| 32 | 62 | 0.80 | 0.70 | − .10 |
| 33 | 46 | 0.91 | 0.90 | − .01 |

Mean difference = − 0.069
S.E. = 0.0402
Difference not statistically significant.

TABLE IV

Inorganic Sulphate Concentration After Hydrocortisone Injection, Closer than Three Months Except When Indicated

| No. | Age | Serum (*Milligrams per 100 Milliliters*) | Synovial Fluid (*Milligrams per 100 Milliliters*) | Difference |
|---|---|---|---|---|
| 34 | 27 | 0.70 | 0.21 | − .49 |
| 35 | 70 | 1.44 | 1.19 | − .25 |
| 36 | 67 | 1.63 | 1.18 | − .45 |
| 37 | 50 | 1.53 | 1.02 | − .51 |
| 1 | 60 | 0.98 | 1.15 | + .17 |
| (4 months later—had been + .31 before treatment with hydrocortisone) | | | | |
| After high salicylate intake | | | | |
| 16 | 75 | 1.49 | 0.36 | −1.13 |
| (had been + .04 before treatment) | | | | |
| 35 | 70 | 1.18 | 1.07 | − .11 |
| (had been + .14 before treatment) | | | | |

serum sulphate and the joint-fluid sulphate was felt to be the important figure, as seen in the tables. In the same way, spinal-fluid sugar and electrolyte values are not complete unless compared with blood values obtained at the same time, preferably in the fasting state.

It will be seen from these illustrations that in recent traumatic synovitis there is no real variation from the values predictable by the dialysate theory. However, in traumatic degenerative hypertrophic arthritis, the values were significantly high and in rheumatoid arthritis, significantly low. In the final group of figures, the effect of treatment has been shown, although the series is not large enough to be analyzed statistically. In this group, both aspirin in moderately high doses and intra-articular hydrocortisone recently injected produced sizeable decreases in the values for joint-fluid sulphate as compared with those for serum sulphate.

## DISCUSSION

As far as we can tell, this is the first demonstration of significant variation of electrolyte values in joint fluid from those predictable by the Donnan membrane equilibrium theory so well advanced by Ropes and Bauer. Yielding has found elevations of anions in fluids from rheumatoid joints, presumably as a result of increased permeability, but none of the fluid values were as high as the serum values, whereas our joint sulphate values in patients with degenerative arthritis consistently exceed the serum sulphate. What are the possible sources of the high sulphate concentrations? It is hard to believe that the synovial membrane secretes this electrolyte and no other. However, the possibility of secretion cannot be dismissed since the hyaluronic acid polymer is secreted, and the process of joint-fluid production may be more complex than we now imagine. An alternative explanation is that degenerating cartilage is the source of the high levels of inorganic sulphate. This theory has the support of the histochemical demonstration of the loss of chondroitin sulphate from the cartilage matrix previously noted. In addition, our next paper will show that this loss of sulphate can take place rapidly in tissue culture.

The diminution of sulphate in joints of patients with rheumatoid arthritis is more difficult to explain, but it may be related to a similar decrease in sugar values[15]. The diagnostic possibilities of this easily performed test should not be overlooked, in conjunction with the more qualitative mucin tests, for differentiating different types of arthritis.

## CONCLUSION

Statistically significant variations in sulphate concentration compared with serum values have been demonstrated, with elevation in established degenerative arthritis and diminution in rheumatoid arthritis. In addition, profound lowering of the sulphate values in both varieties of arthritis after treatment with salicylates or intra-articular hydrocortisone has been indicated in a few cases.

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# The Use of Blade-Guides in Intervertebral-Body Bone-Grafting

BY WALTER P. BARNES, JR., M.D., MACON, GEORGIA

Since Wiltberger reported the dowel intervertebral-body fusion, interest in this method of interbody bone-grafting has brought about the development of instruments different from those previously used. The main feature of the instruments described in this article is accuracy of direction in the absence of direct vision by use of special guides. This assures the surgeon of cutting equally into each vertebral body.

All instruments are operated manually and are made of stainless steel. They consist of three cylindrical saws, five blade-guides, and two obturator nails (Fig. 1). The blades have different breadths for use with varying degrees of interspace narrowing; thus the blade-guide of the correct breadth can be chosen for the proper saw. The blade-guide assures equal cutting into the vertebra above and the one below, and rules out the variability of an undirected instrument. The bevel at the end of the blade allows for ease of introduction and also acts as a safeguard against damage to vessels anterior to the vertebral bodies.

After partial unilateral laminectomy of the vertebrae involved including removal of a portion of the inferior facet of the vertebra above, the nerve root and dura are retracted. The intervertebral disc is incised and enough of it is curetted to allow for the introduction of the blade (Fig. 2). The anterior longitudinal ligament and a portion of the annulus fibrosus anteriorly are left intact so that they act as a stop for the guide. To introduce the guide easily a lamina spreader is used to open the intervertebral space, and the guide is gently pushed forward in an anteroposterior direction until the beveled end rests against the anterior portion of the annulus. The lamina spreader is then removed to allow the vertebral bodies to hold the blade tightly. The choice of saw diameter depends to some extent on the degree of narrowing but is governed principally by ease of safe exposure and size of the individual patient. It is felt unwise to attempt wide exposure at the possible expense of postoperative neurological deficits from prolonged and repeated retraction of the dura and nerve roots. The cylindrical saw is passed over the rod portion of the guide down to the posterior aspect of the vertebral bodies and manually turned clockwise with steady anterior pressure until the guide turns with the saw (Fig. 2). This is a most important step in the procedure. The resistance to the saw abates very sharply when the teeth of the saw encircle the bevel on the guide, thus rendering the guide free to turn with the saw before the teeth reach the anterior cortex of the vertebral body. The operator may also see the exact point of release through the hole in the handle end of the saw. Both instruments are then removed with the slabs of bone, and remaining fragments of disc substance and cartilaginous plates are removed.

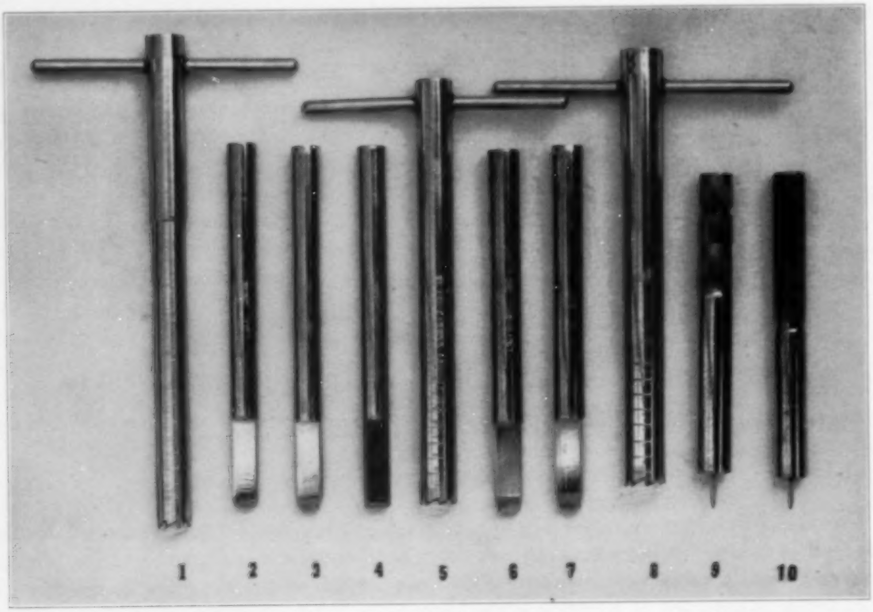

FIG. 1

Photograph of instruments. Numbers 1, 5, and 8 are cylindrical saws of inside diameters 8/16, 9/16, and 10/16 inch respectively. Numbers 2, 3, and 4 are blade-guides with rod diameters of 8/16 and blade thicknesses of 3/16, 4/16, and 5/16 inch respectively. They are used with saw Number 1. Numbers 6 and 7 are blade-guides with rod diameters of 9/16 inch and blade thicknesses of 4/16 and 5/16 inch respectively. They are used with saw Number 5. Saw Number 8 is used only to cut bone grafts while saw Number 5 may be used for taking grafts 9/16 inch in diameter or cutting an intervertebral hole 10/16 inch diameter. Numbers 9 and 10 are obturator nails of 10/16 and 9/16 inch diameter respectively.

The cartilaginous plates are stripped off laterally and toward the midline down to bleeding cancellous bone. This is accomplished by the use of an ordinary curette which, instead of being pulled in the usual manner, is pushed steadily and guardedly to lift the fibrocartilage in the form of a sheet from the underlying bone. A curette with a cutting

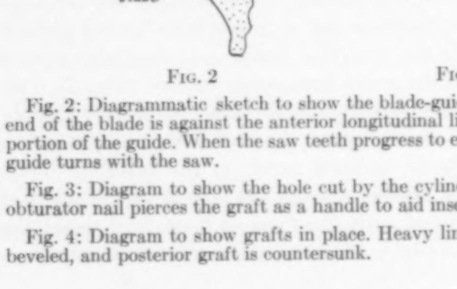
posterior longitudinal ligament
L4
rod
cylindrical saw
L5
anterior longitudinal ligament
sacrum
blade

FIG. 2

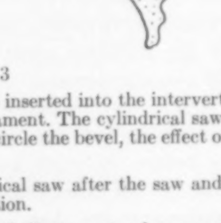

FIG. 3

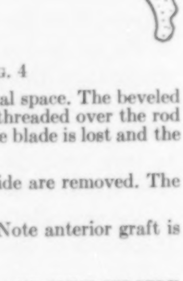

FIG. 4

Fig. 2: Diagrammatic sketch to show the blade-guide inserted into the intervertebral space. The beveled end of the blade is against the anterior longitudinal ligament. The cylindrical saw is threaded over the rod portion of the guide. When the saw teeth progress to encircle the bevel, the effect of the blade is lost and the guide turns with the saw.

Fig. 3: Diagram to show the hole cut by the cylindrical saw after the saw and guide are removed. The obturator nail pierces the graft as a handle to aid insertion.

Fig. 4: Diagram to show grafts in place. Heavy lines indicate cortex for support. Note anterior graft is beveled, and posterior graft is countersunk.

edge three-sixteenths of an inch in diameter seems most satisfactory. A narrow osteotome also aids in complete, even stripping. A short guarded push-pull stroke will work all cartilaginous material off the subchondral bone and also will work through this hard layer to cancellous bone. In some cases there is sclerosis of the subchondral bone and an osteotome is used. Incomplete removal of the plates may delay or prevent fusion. This area is readily accessible through the interspace hole. One side is prepared and grafted before the laminectomy is performed on the other side in order to minimize bleeding from bone.

The basic graft in this procedure is a plug graft. Accessory grafts consist of two lateral semilunar grafts, when the vertebrae are large enough, and one central graft. The obturator nail is used with the proper saw to take plug grafts with cortex on each end from the full thickness of the posterior portion of the ilium. This nail facilitates preservation of cortex and acts as a handle for placing these grafts. Care is taken to avoid fracturing the cortical button on each graft from its underlying cancellous bone. Two plug grafts are placed in each intervertebral hole. The graft to go deepest is slightly beveled on its anterior end and has a strong cortical back (Fig. 3). The graft to go posteriorly has a strong cortex on both ends and is longer than the anterior graft. No difficulty in removing the obturator nail from the graft in the interspace hole is encountered because the grafts and cut surfaces of the vertebrae are rough enough to prevent easy extraction of the graft. After the anterior graft is positioned, a semilunar graft from the iliac crest is pressed into either side of the interspace between the vertebrae, if the lateral recess is large enough to justify the use of this graft. The posterior graft is then pushed into its bed and countersunk about three-sixteenths of an inch.

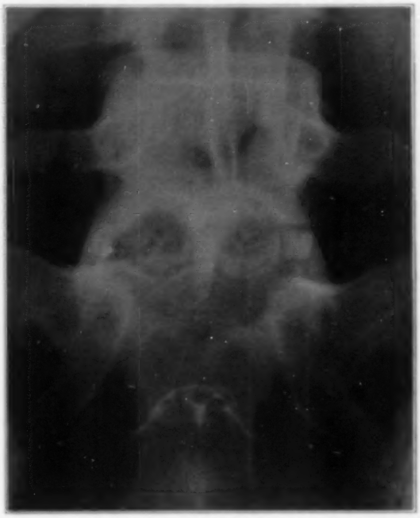

Fig. 5

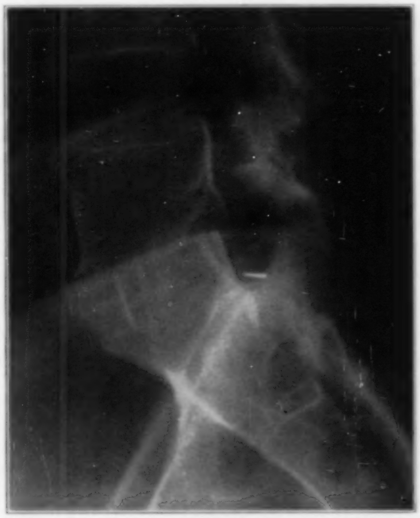

Fig. 6

Fig. 5: Postoperative anteroposterior view of the lumbosacral joint showing bone grafts in place.

Fig. 6: Postoperative lateral view of the lumbosacral joint of the same patient.

On the opposite side a partial laminectomy is done as before and the interspace hole is cut. The cartilaginous plates and disc material are thoroughly removed as was done on the other side. Particular attention is directed to the ridges of bone between the right and left holes. Both ridges are thoroughly removed to create a bed for the central graft. After the anterior plug graft and the semilunar graft are placed, a central graft is wedged against the previously placed plug grafts on the completed side. The posterior plug graft is then placed and countersunk. The central graft is taken from between two holes in the ilium created when removing the plugs, so that the concave surfaces of this graft match the convex surfaces of the plug grafts in the interspace. The grafts are put in with the vertebrae spread and are locked in place when the spreader is removed and the spine is extended to the normal position (Fig. 4). It is felt that grafts with strong intact cortex are essential for proper support during the time required for revascularization of the grafts, and that either too much cancellous or cortical bone might lead to failure.

Guided instruments for intervertebral-body bone-grafting are presented and the technique for their use is described. Credit is given to Wiltberger for the idea of dowel-type grafts and it is believed that the use of exacting guides will improve the success of this type of procedure. The described instruments have been used for approximately two years. The majority of the thirty-five patients upon whom this procedure was performed had degenerated discs with pain of longstanding. A few had congenital deformities such as spondylolysis. Five patients required bone grafts at the fourth and fifth lumbar interspace and at the fifth lumbar and first sacral interspace. The remainder has required grafting at the fifth lumbar and first sacral interspace only. Neurological deficits of minor degree are relatively frequent in the immediate postoperative period. These include loss of, or diminished, Achilles tendon reflex, and diminished sensation to pinprick and touch, usually at the lateral aspect of the foot (first sacral-nerve root). Of thirty-five patients, minor deficits have persisted unilaterally in twelve patients. These deficits do not cause the patient any discomfort. Two patients have had transitory weakness of toe extensors unilaterally which abated within three or four months. One patient had transitory unilateral anterior tibial, peroneal, and toe-extensor weakness. Strength was restored at the end of six months. Fusion usually is complete by the end of the fourth postoperative month, and may occur sooner. From this small series of patients no exact conclusions should be drawn because a longer postoperative follow-up study would be far more valuable and accurate. However, of the patients operated upon six months ago or longer, 95 per cent show fusion, and it is expected that this percentage will increase. Long-term results will be reported later.

NOTE: The author acknowledges with appreciation the invaluable help of Dr. Robert A. Clark, Jr., neurosurgeon, in the development of this procedure.

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# Neurilemoma Involving Bone

BY MAYNARD S. HART, M.D., AND W. COMPERE BASOM, M.D., EL PASO, TEXAS

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Unfortunately, there exists considerable uncertainty in the classification of tumors of the peripheral nervous system; such terms as Schwannoma, neurogenic sarcoma, neurofibroma, malignant Schwannoma, neurinoma, perineural fibroblastoma, and neurofibrosarcoma appear in the literature and most certainly can only be confusing to most physicians.

This case is presented to describe the gross and microscopic characteristics and biological behavior of neurilemoma.

The patient, a white male, forty-six years old, had played baseball on June 23, 1955. While he was at bat he swung at the ball and missed. His right lower extremity collapsed under him in a deformed position and he fell. He was in extreme pain. The patient was taken immediately to the hospital and the extremity was found to be in marked external rotation with shortening, and the right thigh was swollen. The slightest movement of the extremity caused severe pain.

Roentgenograms were made in the best position possible, and the limb was placed in adhesive traction. Roentgenograms revealed a long oblique fracture of the upper one-third of the right femur with a fairly sharply demarcated, cystic-like area in the line of the fracture (Fig. 1). An open reduction was done. Fixation of the oblique fracture in the upper third of the femur was obtained by use of a Smith-Petersen nail, the extra long trochanteric anchor plate of which extended well below the level of the fracture (Figs. 4 and 5).

The cystic area, which was approximately three centimeters in greatest diameter, was situated at the nutrient foramen. There was a yellowish-gray, encapsulated, dumb-bell shaped tumor extruding through the cystic area. The greater portion of the tumor was situated outside the bone and distorted the adjacent soft tissues and muscle. The tumor measured approximately eight centimeters in diameter. The tumor was dissected with relative ease; the greater portion of the tumor was adjacent to the muscle belly of the vastus intermedius. A nerve trunk could be seen entering the tumor on its superior medial aspect. The patient had an uneventful postoperative course, and follow-up observations revealed no evidence of recurrence to the present time (Figs. 6 and 7).

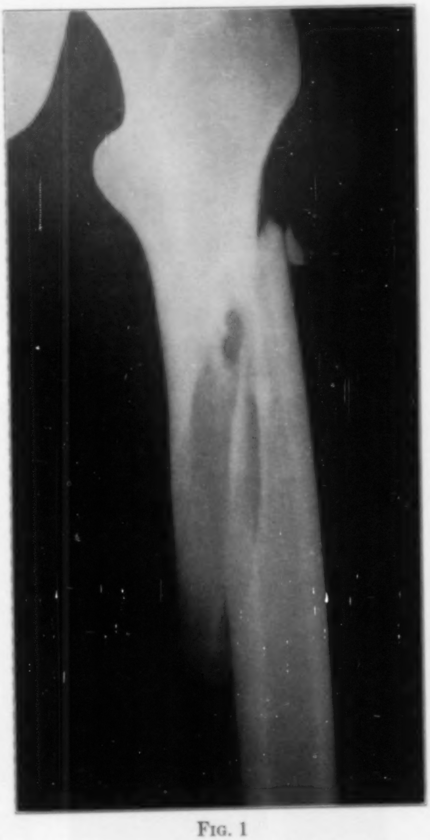

FIG. 1

Portable roentgenogram of lesion made on admission to the hospital.

The past history revealed that in February 1952 the patient had had pain in the lower back extending down the right thigh. At that time the patient had complained of numbness of the right thigh; the extremity had felt as though it were "asleep." A diagnosis of a herniated intervertebral disc had been made, but additional studies at another hospital had not confirmed this. The patient had been told that he had a "muscular nervous condition," and he had been given "injections" for about two weeks. The patient had improved and had had no further complaints.

The gross specimen submitted to the laboratory consisted of a well encapsulated, firm, dumb-bell

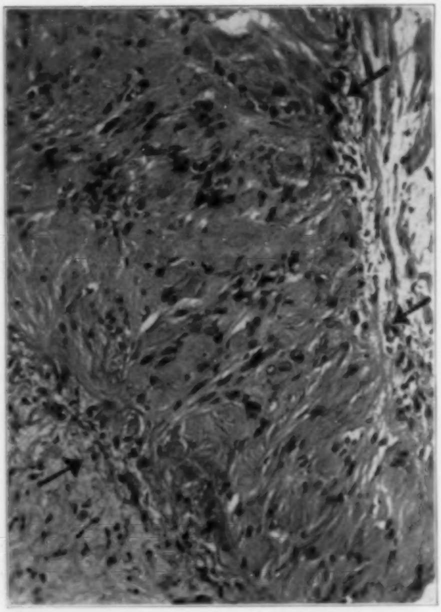

FIG. 2

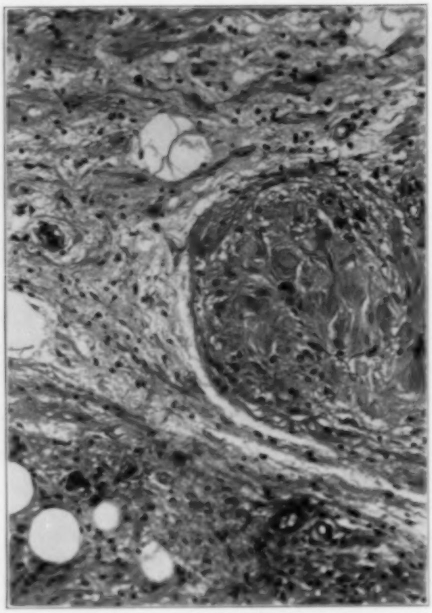

FIG. 3

Fig. 2: Alignment of nuclei in Verocay body (arrows) (Courtesy of Lauren V. Ackerman, St. Louis, Missouri).

Fig. 3: The organoid pattern is shown, and thick-walled small vessels are seen (Courtesy of Lauren V. Ackerman, St. Louis, Missouri).

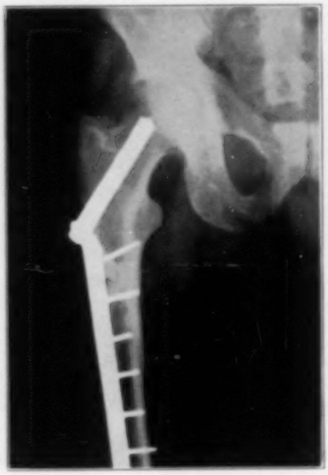

FIG. 4

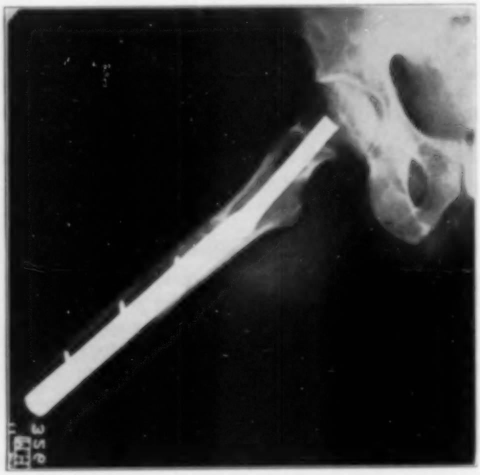

FIG. 5

Fig. 4: Anteroposterior roentgenogram of the femur with the trochanteric anchor plate in place.

Fig. 5: Lateral roentgenogram made with extremity in flexion.

shaped tumor. The specimen measured eight centimeters in its greatest diameter. On sectioning, there was found distinct lobulation of the tissue with fibrous trabeculations separating yellowish-gray, firm tissue, but there were many various sized, cystic areas, measuring up to two centimeters scattered throughout. These were filled with a thin, slightly blood-tinged, mucoid fluid. The cystic linings were smooth. A small nerve could be identified at one pole of the mass; this blended into the tumor.

The microscopic examination of multiple sections showed interlacing strands of cells with elongated

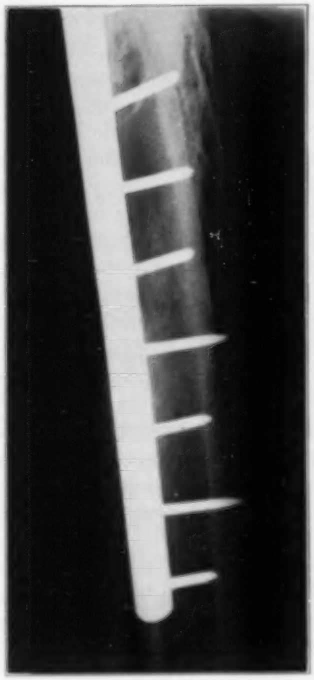

FIG. 6

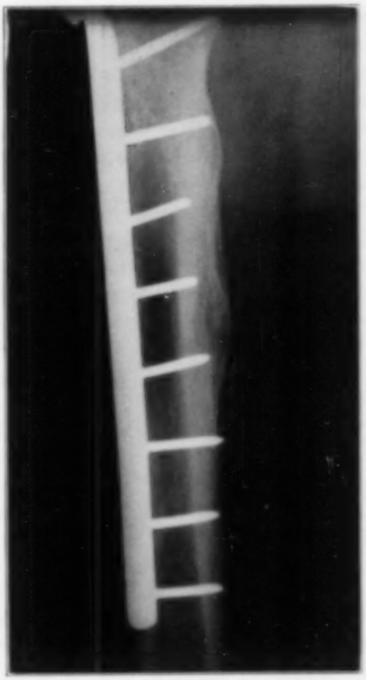

FIG. 7

Fig. 6: Roentgenogram showing union of fracture and minimal bone reaction.

Fig. 7: Roentgenogram made twenty months after operation.

nuclei, often arranged in gentle whorls and sometimes showing typical palisading of the nuclei. In addition, there were typical Verocay bodies and Antoni A and B tissue (Fig. 2). All of the sections showed scattered, thick-walled vessels interspersed throughout and delicate strands of connective tissue which produced the lobular pattern (Fig. 3).

The pathological diagnosis was neurilemoma.

The microscopic slides in this case were submitted to Dr. Lauren V. Ackerman at Barnes Hospital, St. Louis, Missouri; he concurred in the diagnosis of neurilemoma.

From the location of this lesion we believe that this tumor arose from a nerve filament which entered with the nutrient vessel of the bone, producing a destructive lesion at the nutrient foramen which resulted in a dumb-bell shaped tumor. As such, the lesion could be classified as an intramedullary neurilemoma of the femur.

For a complete classification of tumors of the peripheral nervous system one must refer to the *Atlas of Tumor Pathology*, Section 2, Fascicle 6, "Tumors of the Peripheral Nervous System" by Dr. Arthur Purdy Stout. The neuroma is a proliferative mass of Schwann cells with mixed elements and it is not a true neoplasm. It is simply a mass of scar tissue in which there is an admixture of axis cylinders. There have been no reports of true neoplasms developing from a neuroma [3]. The neurofibroma is a true neoplasm comprising a proliferation of Schwann cells with an admixture of neurites. At certain stages of development the traumatic neuroma may resemble very closely the histological pattern of the neurofibroma [6]. Many bizarre histological patterns are encountered.

The solitary neurofibroma is a relatively common tumor of the soft parts, but is extremely rare in bone. When the neurofibroma does occur inside the bone, there may be extensive destruction and deformity by pressure.

A malignant, metastasizing Schwannoma is the malignant variant of neurofibroma and may occur in the course of von Recklinghausen's disease. Metastasis is usually through the blood stream, and the lymphatics are rarely involved. The term *Schwannoma* should be reserved for those tumors considered malignant. The terms *neurogenic sarcoma* and *neurofibrosarcoma* should be discarded.

The neurilemoma is the true benign nerve-sheath tumor: this lesion apparently occurs only on very rare occasions within the bone, although the lesion is fairly common in peripheral, cranial, and sympathetic nerves. The neurilemoma may occur at any age, and the lesion occurs with equal incidence in each sex. The tumor may arise from any nerve or nerve root that has a sheath of Schwann cells, and the lesion is usually fairly solid. There is a distinct encapsulation in contrast with the neurofibroma. As the lesion enlarges, cystic changes are characteristic. The cystic areas are frequently filled with a pale yellow, translucent fluid. The lesions rarely recur if completely excised. Histologically, the neurilemoma shows a characteristic pattern characterized by Schwann cells arranged in delicately formed interlacing bands or strands separated by fairly compact connective tissue. The nuclei often assume an organoid pattern, and other areas will show irregularly clustered Schwann cells interspersed throughout a loosely arranged reticular stroma. The more compact cellular areas with the organoid pattern are referred to as Antoni Type A tissue, and the loosely arranged areas are referred to as Antoni Type B tissue. Both the clinical and pathological facts concerning the neurilemoma were published as early as 1935 by Dr. Stout.

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# Benign Osteoblastoma of the Talus

## A Review of the Literature and Report of a Case

BY NICHOLAS J. GIANNESTRAS, M.D., AND JACK R. DIAMOND, M.D., CINCINNATI, OHIO

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Benign osteoblastoma is the term used by Jaffe to denote an uncommon neoplasm of bone characterized by vascular osteoid and bone-forming matrix rich in osteoblasts[7]. Relatively few cases of this tumor are reported in the literature.

### HISTORY AND NOMENCLATURE

In 1932, Jaffe and Mayer presented a comprehensive report of an osteoid and bone-forming tumor of a metacarpal bone. To these authors the condition presented problems of nomenclature and classification: they recognized the possibility of relationship of this lesion to Virchow's osteoid chondroma, as well as to two somewhat similar tumors described by Bergstrand in 1930.

Lichtenstein, in 1952, used the name *osteogenic fibroma* to denote a group of tumors with active osseous proliferation in a highly vascular connective-tissue stroma in which there was osteoclastic resorption and remodeling. Other benign osteoid tissue-forming tumors of bone he described as slowly developing with a predilection for the bones of the hand and foot and showing a sudden spurt in growth without becoming invasive or frankly malignant. Their salient features were an abundance of osteoid in a background of osteoblastic connective tissue. Into this group he placed the case reported by Jaffe and Mayer, as well as the two cases reported by Bergstrand.

In 1954, Golding and Sissons reported two instances of osteogenic fibroma which involved the vertebral column. They expressed the opinion that these lesions were closely comparable to Lichtenstein's description of osteogenic fibroma, as well as to Jaffe and Mayer's case involving the metacarpal bone.

In the same year, Dahlin and Johnson reported eleven cases of benign osteoid tumors under the name *giant osteoid-osteoma*. They concluded that both lesions contained the same elements and could well be identical.

Jaffe, in 1956, in a comprehensive review advocated the use of the name *benign osteoblastoma*. He objected to the name *osteogenic fibroma* not only because of the paucity of fibromatoid elements present in the lesion, but especially because of the possibility of confusion with ossifying fibroma, the latter term being commonly used to represent a solitary focus of fibrous dysplasia in the mandible or another facial bone. The name *giant osteoid-osteoma* he dismissed on the ground that its use might well tend to "blur the well-established clinicopathological entity of osteoid osteoma."

At about the same time, Lichtenstein[13] reported that for all practical purposes these tumors comprise a single category of benign tumors. Furthermore, he accepted the name *benign osteoblastoma* in view of the objections to the use of the term *fibroma*.

Dahlin and Johnson contended that Sherman's Case 1 in her series of osteoid-osteoma is yet another example. Several cases among those reviewed in this paper were diagnosed from study of the biopsy specimen as sarcoma, and in one instance amputation was performed[4]. Jaffe reported the same diagnosis in several cases involving the vertebral column, where, fortunately, radical surgical procedures were precluded and recoveries resulted after conservative measures[7]. The case described in this paper was first diagnosed by the pathologist as a solitary focus of fibrous dysplasia.

One cannot help but be impressed by an occasional case, presented in the literature as a more or less atypical osteoid-osteoma and giant-cell tumor, which clearly resembles osteoblastoma in a more than superficial manner[2,3,11,14,15,16].

## NATURE

Osteoblastoma is in all probability neoplastic[4,6,7,10,12,13]. This is apparent histopathologically and by a tendency to progressive enlargement[7]. Its curability with incomplete or piecemeal removal, or with relatively small doses of roentgen rays attests to its benign nature[6,7].

## CLINICAL CONSIDERATIONS

### *Incidence*

Osteoblastoma is relatively rare[7]. If one includes Jaffe and Mayer's case, the two reported by Bergstrand, and the one presented below, only twenty-nine cases have been reported. It seems well, however, to reduce this to twenty-seven by eliminating Bergstrand's cases, which are equivocal at best[6]. Jaffe states that he has had experience with about twenty cases, ten from his own institution and approximately the same number from outside sources[7].

With respect to age, the incidence appears to be highest in the second decade of life, although cases have been reported in both younger and older patients[4,7,12]. Jaffe claims a predilection of the disorder for females[7]. Lichtenstein observes no predisposition for the lesion to occur in either sex more frequently[12]. The cases reviewed here indicate a greater incidence among males.

As reports have accumulated it appears that no bone can be considered invulnerable and that the long tubular bones are involved just as frequently as other bones[12] (Table I).

### *Clinical Complaints and Findings*

The symptoms are those of a benign osseous tumor. Pain tends to be constant and boring and is located over the part affected, but it may be referred to a nearby joint. Nocturnal exacerbation of the pain is sometimes reported. Local tenderness is usually present, but is ordinarily not severe. There may be local swelling and a palpable mass. Intermittent swelling of a nearby joint has been reported[4]; limp is not unusual. Muscle atrophy and weakness of the affected extremity may be present. Weight loss may occur due to anorexia resulting from constant pain. Increased local temperature is not uncommon. When the vertebral column is involved, neurological signs and symptoms of gradual spinal-cord compression may be present. These include referred pain, paraesthesia, weakness, and eventual paraplegia. When spinal-cord compression is present the spinal fluid exhibits no abnormalities.

The laboratory findings are invariably normal. Elevation of the erythrocyte sedimentation rate has been noted in a few cases[4].

The roentgenographic findings are not distinctive. The picture varies with the size, location, degree of calcification, and vascularity of the lesion. The bone is apt to be expanded, and the cortex over the lesion may be greatly thinned, completely eroded away, or the site of a pathological fracture. However, a thin shell of periosteal new bone is customarily present to delimit the tumor[4,12]. The neighboring bone may show a rather thin layer of sclerotic thickening. The lesion may be as small as one or two centimeters or as large as seven to ten centimeters in diameter[7]. If the lesion is highly vascular it appears lightly calcified and quite radiolucent. In the less vascular type it is radiopaque, mottled, and highly calcified. In rare instances a nidus of dense bone in the central area of the lesion may be present[12]. The tumors tend to be eccentric in location, and they may occur anywhere in the bone. Roentgenograms chiefly demonstrate a variation from normal and indicate a need for further investigation.

TABLE I

CLINICAL FEATURES OF BENIGN OSTEOBLASTOMA

| Case | Age | Sex | Location of Lesion | Duration of Symptoms | Pain | Tenderness | Tumor | Limp | Local Heat |
|---|---|---|---|---|---|---|---|---|---|
| 1 * | 15 | F | 4th metacarpal | 3 yrs. | x | | x | | |
| 2 † | 17 | M | Talus | 3 yrs. | x | x | x | x | x |
| 3 † | 20 | M | Middle third of tibia | 4 yrs. | x | | | | |
| 4 † | 23 | M | Distal third of femur | 1 yr. | x | | x | | x |
| 5 † | 31 | M | Patella | 4 yrs. | x | | x | | |
| 6 † | 19 | M | Proximal third of tibia | 4 yrs. | x | | x | | |
| 7 † | 60 | M | Middle third of humerus | 1 yr. | x | x | x | | |
| 8 † | 18 | M | Proximal third of femur | 5 mos. | x | x | | | |
| 9 † | 16 | M | L 3 | 2½ yrs. | x | x | | | |
| 10 † | 20 | M | T 3 | 1½ yrs. | x | | | | |
| 11 † | 5 | M | T 5 | 3 mos. | x | x | | x | |
| 12 † | 24 | F | T 11 | 1 yr. | x | | | | |
| 13 ‡ | 14 | F | C 7 | 6 mos. | x | x | | x | |
| 14 ‡ | 14 | F | L 3 | 1 yr. | x | | | Paralysis | |
| 15 § | 13 | M | T 8 and T 9 | 3 mos. | x | | | | |
| 16 ‖ | 19 | F | Talus | 6 mos. | x | x | | | |
| 17 ¶ | 6 | | Lower metaphysis of femur, 1 | From a few months to several years | Pain, tenderness, or swelling | | | | |
| 18 ¶ | 9 | | Tibial shaft, 2<br>Distal portion of radius, 1 | | | | | | |
| 19 ¶ | 12 | | Vertebrae, 4<br>Metatarsal, 2 | | | | | | |
| 20 ¶ | 14 | | Temporal bone, 2 | | | | | | |
| 21 ¶ | 16 | | | | | | | | |
| 22 ¶ | 18 | | | | | | | | |
| 23 ¶ | 18 | | | | | | | | |
| 24 ¶ | | | | | | | | | |
| 25 ¶ | | | | | | | | | |
| 26 ¶ | | | | | | | | | |
| 27 ¶ | | | | | | | | | |

* Case of Jaffe and Mayer, 1932

† Cases of Dahlin and Johnson, 1954

‡ Cases of Golding and Sissons, 1954

§ Case of Kirkpatrick and Murray, 1955

‖ Case of Giannestras and Diamond, 1957

¶ Cases of Lichtenstein, 1957

## GROSS AND MICROSCOPIC APPEARANCE

Grossly, benign osteoblastomata are hemorrhagic, and operative bleeding is often impressive[4]. They vary in size from one to ten centimeters and in color from pink to red or purple[7]; they are usually eccentric; and the overlying cortex is greatly attenuated or even completely eroded away. When the cortex is attenuated or eroded, the bulging periosteum is intact, except when a vertebra is involved[4]. In consistency they are described as granular or gritty and friable[4,7]. Some areas may be firm or sclerotic due to heavier calcification while others may be soft or cystic. The tumor is usually demarcated by a narrow zone of reactive sclerosis due to the formation of new subperiosteal and endosteal bone.

Microscopically one sees long, broad, and widely separated osteoid trabeculae of considerable uniformity and in a fairly regular pattern. The areas between are largely filled with dilated capillaries or free collections of blood-filled spaces. The capillaries are lined with endothelium while in other areas where blood is present there are no visible vessel walls. The recognizable vessels are thin walled and usually lack a muscle component[4]. Between the trabeculae and the vascular channels are cords, nests, and sheets of osteoblasts in a scanty, loose connective tissue containing a few mature fibroblasts and small amounts of collagen. Multinucleated giant cells are present in varying numbers. They are smaller and contain fewer nuclei than those of a benign giant-cell tumor. They lie in the loose connective tissue, in the vascular spaces, or apposed to the trabeculae, where they seem to be engaged in osteoclastic activity[4,7]. The degree of calcification of the trabeculae varies considerably, but it is usually rather light. When it is heavy, the lesion is less cellular[7]. Occasionally calcification may be quite heavy and the osteoid trabeculae may demonstrate conversion to bone[12]. Mitotic figures are rare and no cytological evidence of malignancy has been definitely demonstrated in any of the cases reviewed.

## DIFFERENTIAL DIAGNOSIS

It seems virtually impossible to diagnose benign osteoblastoma without benefit of histopathological studies of the material. Roentgenography is not characteristic. None of the cases reviewed were correctly diagnosed before biopsy, curettement, or excision; and, even then, diagnostic errors were common.

*Osteoid-osteoma:* Benign osteoblastoma probably most closely resembles osteoid-osteoma[6]. Osteoblastoma contains a larger number of osteoblasts, however, and also tends to be a consistently larger lesion[7]. Osteoid-osteoma tends to produce considerable reactive sclerosis in surrounding bone, whereas osteoblastoma produces only a narrow zone of increased density or even a certain amount of bone destruction. The structure of the material of osteoblastoma is more irregular and more imperfectly differentiated than that of osteoid-osteoma, and in particular, the continuous network of bone and osteoid trabeculae composing the nidus of the latter is usually absent. Somewhat more fibrous tissue may be present in osteoblastoma[6,10]. A few clinical points serve in conjunction with the histopathological features to further the differentiation. The pain is more severe in osteoid-osteoma; furthermore, there is a tendency toward containment to a small and relatively constant size, in contrast to the quality of growth and size seen in osteoblastoma. In a roentgenogram this difference is exemplified by the zone of increased density surrounding the former lesion as opposed to the erosion and destruction of contiguous bone seen in the latter[6,7,10].

*Osteogenic sarcoma:* An erroneous diagnosis of osteogenic sarcoma can result in unnecessarily radical surgery. This error has occurred in the past, resulting in needless amputation. It is of importance, therefore, to be able to distinguish with certainty between the two entities. The cellularity of osteoblastoma coupled with the rapid production of osteoid in the lesion may well account for the possible histological confusion[7].

TABLE II

Diagnostic Difficulties Encountered in Benign Osteoblastoma

| Case | Preoperative Diagnosis | X-ray Diagnosis | Initial Pathological Diagnosis |
|---|---|---|---|
| 1 | Probable osteogenic sarcoma | Probable osteogenic sarcoma | Osteogenic sarcoma |
| 2 | | | Osteogenic fibroma |
| 3 | | Old osteomyelitis | Atypical hemorrhagic so-called osteoid-osteoma |
| 4 | | Osteomyelitis or possible malignant tumor | Osteogenic sarcoma |
| 5 | Internal derangement of knee | Osteolytic lesion of patella | Atypical giant-cell tumor |
| 6 | | Chronic osteomyelitis or malignant tumor | Giant-cell tumor of low grade of malignancy |
| 7 | Tumor | Sarcoma | Osteoma containing foreign-body giant cells |
| 8 | | Osteomyelitis | Benign giant-cell tumor |
| 9 | | Osteoma | Foreign-body giant-cell tumor |
| 10 | | | Osteosarcoma |
| 11 | | Inflammatory or neoplastic destructive process | |
| 12 | | | |
| 13 | Osteogenic sarcoma | | Osteogenic sarcoma |
| 14 | Osteoclastoma | | Osteogenic sarcoma or active and disorderly osseous granulation tissue |
| 15 | | | |
| 16 | Defect of talus, cause unknown | Area of rarefaction of talus, cause unknown | Fibrous dysplasia |
| 17 through 27 | Not given | Not given | Not given |

In spite of this cellularity, however, the atypical and irregular cytological features of a malignant tumor are lacking[6]. Mitoses are rare. Sarcoma giant cells, tumor cartilage, and the large, plump, sarcomatous connective-tissue cells are absent, and the cells enmeshed in the osteoid trabeculae are small and regular[7].

*Giant-cell tumor:* Jaffe feels that confusion between giant-cell tumor and osteoblastoma is the result of placing undue emphasis on the presence of the multinucleated giant cells regularly found in osteoblastoma. He states that in view of the clearer understanding of giant-cell tumor reached in recent years, the mistake should be less frequent than it once was[7]. The plump, spindle-cell stroma prominent in giant-cell tumor is absent in osteoblastoma. Osteoid is either absent or at least inconspicuous in the former as compared with the broad trabeculae in the latter[4]. In addition, the sites of predilection differ when long bones are involved; giant-cell tumor almost invariably occurs at the ends of the bones and osteoblastoma anywhere within their length[13].

*Others:* Because they have been confused with osteoblastoma, several other lesions merit brief mention. According to Dahlin and Johnson, aneurysmal bone cysts bear a certain similarity and hemangioma could also be considered a likely diagnosis[4]. In the case to be presented the diagnosis of fibrous dysplasia was made by the pathologist and only upon review of the curetted material by Jaffe[8], and by the Armed Forces Institute of Pathology[16], was the diagnosis of benign osteoblastoma reached (Table II).

## TREATMENT AND PROGNOSIS

Treatment should be conservative, in keeping with a benign tumor. Curettement of small to moderate lesions followed by packing of the defect with bone chips seems to

TABLE III

METHODS OF TREATMENT USED,
LENGTH OF FOLLOW-UP, AND RESULTS OBTAINED

| Case | Treatment | Length of Follow-up | Results of Treatment |
|---|---|---|---|
| 1 | Total excision | 1½ yrs. | No recurrence, relief |
| 2 | Resection | 1 yr. | No recurrence, relief |
| 3 | Resection and modified triple arthrodesis | 6½ yrs. | No recurrence, relief |
| 4 | Amputation | 4½ yrs. | No recurrence, relief |
| 5 | Patellectomy | 3½ yrs. | No recurrence, relief |
| 6 | Curettement and postoperative x-ray therapy | 19 yrs. | No recurrence, relief |
| 7 | Curettement, x-ray, radium | 10 yrs. | No recurrence; died after prostatic resection 10 years after surgery |
| 8 | Curettement (twice) and x-ray therapy | 13 yrs. | No recurrence, relief |
| 9 | Excision and curettage, x-ray therapy | 14 yrs. | No recurrence, relief |
| 10 | Subtotal excision, x-ray therapy | 14 yrs. | No recurrence, relief |
| 11 | Subtotal resection | 1 yr. | No recurrence and symptoms, including neurological, subsiding |
| 12 | Total excision | 7 yrs. | No recurrence, relief |
| 13 | Excision and x-ray therapy |  | No recurrence, symptom-free when last seen |
| 14 | Excision and x-ray therapy | 6 yrs. | No recurrence, symptom-free when last seen |
| 15 | Excision and x-ray therapy | 7 yrs. | Good general health when last seen |
| 16 | Curettement and bone chips | 1 yr. | Complete recovery, no recurrences |
| 17 through 27 | Conservative surgical treatment in 10; limited biopsy in 1; x-ray therapy in at least 1 | From 7 mos. to 3 yrs. | In 9 of 11 cases no recurrence. In one case, recurrence with possible malignant change after 9 years. In one case treated by limited biopsy, cortical defect healed, and no change noted in size of lesion 14 months later. |

be the treatment of choice. Removal of a wide margin of normal bone does not seem to be necessary, although complete excision, when surgically feasible and technically easy, seems also to yield good results and is not contra-indicated. When incomplete or piecemeal removal is performed, as in some instances involving the vertebral column, postoperative roentgen therapy in modest doses has successfully arrested the process and permitted calcification and healing of the residual portions of the tumor[4,10]. When spinal-cord or nerve-root compression is a factor, total removal may be impossible; enough tissue, however, should be removed to accomplish decompression[12] and roentgen therapy should be given postoperatively. Following such treatment, four of the patients in the cases reviewed experienced local recurrences. In one instance when a vertebra was involved, further irradiation sufficed to produce arrest and calcification [10]. In another involving the femur, curettement and irradiation were sufficient to eradicate the recurrence. In a case described by Lichtenstein the treatment consisted in removal of only the central ossified focus without curettement. Roentgenograms made fourteen months later showed the cortical defect to be repaired and the lesion to be of unchanged size[12]. In yet another case described by the same author and involving a vertebra, the tumor recurred locally nine years after piecemeal removal and roentgen therapy. The microscopic examination of the recurring lesion showed a distinct increase in cellularity and in the size of the nuclei of the osteoblasts. These changes were not considered frankly malignant; however, a guarded prognosis was given and a close follow-up anticipated[13].

When spinal-cord or nerve-root compression is present, the degree of recovery from the resulting neurological disturbance seems to depend on the same factors present in recovery from any other slowly progressing compression, namely, the degree and duration of compression, and the thoroughness of the decompression.

The prognosis is usually good, although local recurrences may occasionally occur. Malignant changes and metastases have not been demonstrated conclusively to the present time. However, metastases eventually may be encountered as more information on benign osteoblastoma accumulates (Table III).

## CASE REPORT

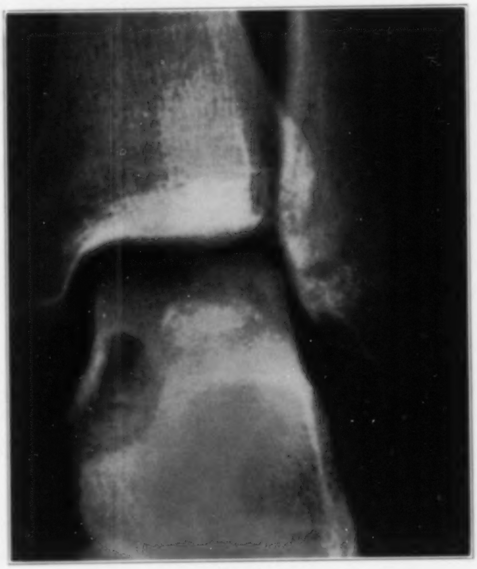

FIG. 1

The patient, a nineteen-year-old Negro girl, was first seen November 19, 1954. The chief complaint was a painful ankle. Several months before, the ankle had been injured during athletic activities. Strapping had failed to relieve the pain. Six weeks before a diagnosis based on the roentgenogram had been made of a chip fracture of the posterior aspect of the talus. Sufficient time had elapsed to permit healing of a chip fracture. Pain had not subsided but had become progressively more severe. The only relief, however, had been afforded by walking—even this was transitory. If she remained inactive for any period of time, the pain in the ankle became unbearable. She had not observed swelling in or about the ankle joint.

She was well developed and well nourished, and she walked with no apparent discomfort. There was a sharply localized area of tenderness over the anterior aspect of the ankle at the level of the joint when the foot was held in a position of plantar flexion. On dorsiflexion of the foot the area of tenderness disappeared. No masses were palpable and motions in the ankle and the subtalar articulations were normal. No effusion into the joint could be detected nor was there any thickening of the periarticular tissues. A tentative diagnosis of pinched synovial tab was made, and one cubic centimeter of hydrocortone was instilled into the ankle joint. When seen again one month later, the patient reported that the pain had been relieved for forty-eight hours. Three additional injections of hydrocortone during the next six weeks resulted in relief of pain but only temporarily. Within a period of another six weeks, however, the patient wrote from school stating that the discomfort in her ankle was so intense that she was returning for further care. On February 12, 1955, further roentgenograms were made with the ankle in various positions, and an area of rarefaction of the bone approximately 1.5 centimeters in diameter in the medial and anterior portion of the talus was observed (Fig. 1).

The patient was hospitalized. On February 22, 1955, under general anaesthesia, the neck of the talus was exposed. In this area of the bone a defect containing friable, reddish, granulomatous-appearing material was found. The defect was thoroughly evacuated by curettage and then filled with bone chips obtained from the tibia. The extremity was immobilized in a leg cast following surgery for a period of six weeks. After removal of the cast, gradually increasing use of the extremity was permitted.

The pathologist's report of the histopathological examination of the material curetted from the talus described it as consisting of a number of small pieces of gritty tissue and small bone spicules. Microscopically the tissue was described as quite vascular and rich in cells. The cellular component was interpreted as representing plump histiocytes with eccentric nuclei. Whorls and interlacing fascicles of fibrous tissue and irregular, atypical trabeculae of partially calcified osteoid were noted. Multinucleated giant cells in close relationship to the osteoid were present in moderate numbers. A few foam cells and some iron pigment was also seen. The diagnosis rendered was that of fibrous dysplasia.

Review of the slides and roentgenograms by Jaffe and by the Armed Forces Institute of Pathology resulted in discarding the diagnosis of fibrous dysplasia in favor of that of benign osteoblastoma[9,17].

The report of Jaffe is as follows: "Microscopically, the tissue has much in its pattern to suggest an osteoid-osteoma. However, the clinical history is atypical for osteoid-osteoma, and so is the large size of the lesion. Such lesions have been designated as giant osteoid-osteoma. However, that term introduces a confusion, and since the basic cells of the lesion are osteoblasts, I have chosen to call a lesion of this type a benign osteoblastoma. The lesion is entirely benign. No additional treatment is indicated. The condition bears no relationship whatever to osteoid-osteoma."

The report from the Armed Forces Institute of Pathology is as follows: "The staff regard the lesion as belonging in the group for which the term *osteoblastoma* has been used for some time by Jaffe. His views have just been published in the *Bulletin for the Hospital for Joint Diseases* in October 1956. The same month

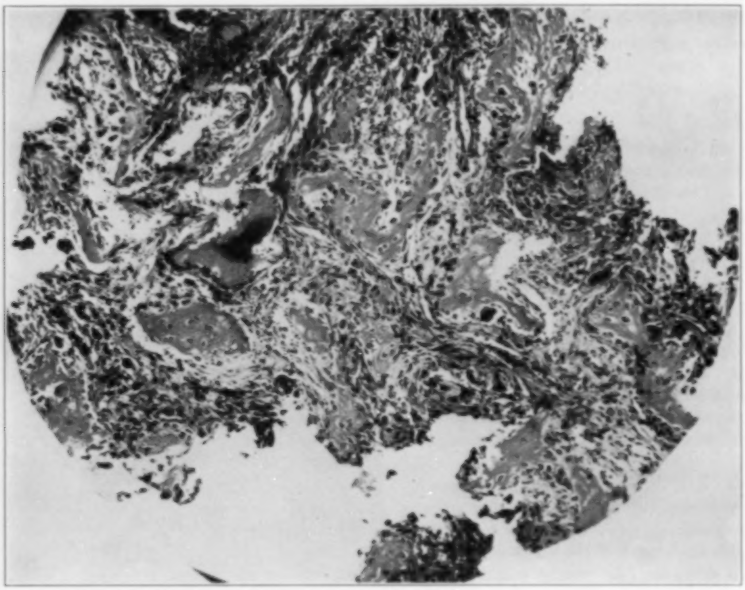

FIG. 2

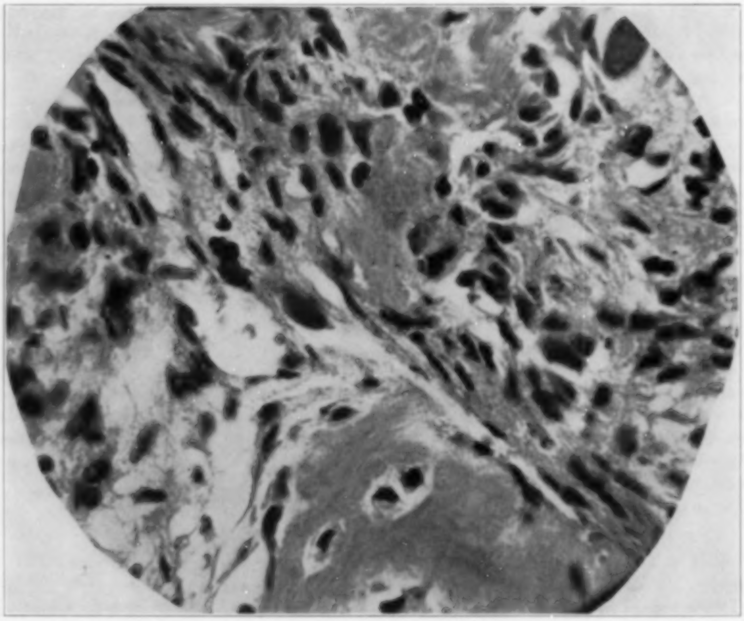

FIG. 3

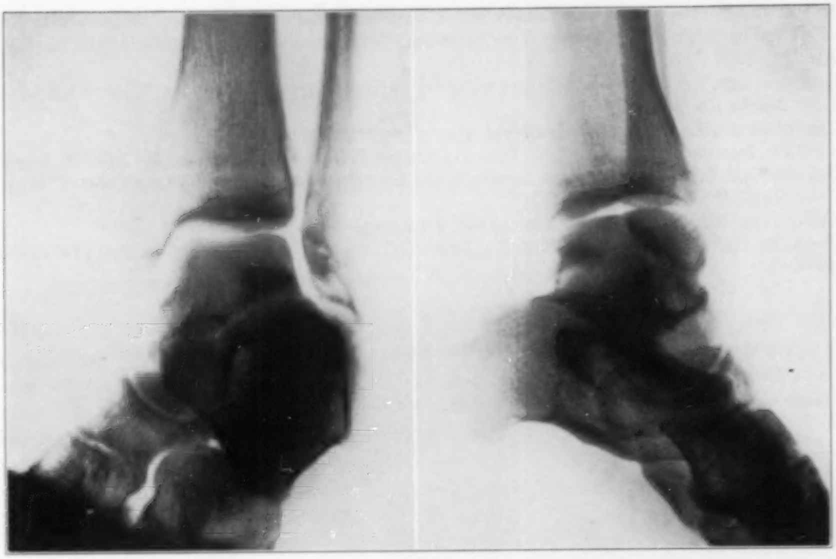

FIG. 4

Lichtenstein published a similar article with similar views in *Cancer*. Prior to that time the lesion had been commented upon and described under the term *giant osteoid-osteoma* by Dahlin and Johnson: Giant Osteoid Osteoma. *The Journal of Bone and Joint Surgery*, 36-A: 559, 1954. This latter term is of course unsatisfactory since the lesion has no relationship to the true osteoid-osteoma but is a neoplasm in its own right. The lesion is generally benign. The staff believe that the material in this particular case falls into that entity. Accordingly, it has been so diagnosed."

The patient was last seen on December 20, 1957, at which time there was no evidence of recurrence and she was asymptomatic (Fig. 4).

## DISCUSSION

It is apparent from this case that an important step in the diagnosis of benign osteoblastoma is the proper identification of the outstanding cellular component, at first erroneously identified as histiocytes instead of osteoblasts. Undue emphasis upon the fibrous-connective-tissue elements present seems to have given further support to the first diagnosis. This case emphasizes the difficulties encountered in histopathological analysis of lesions of this type.

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# Bilateral Recurrent Posterior Dislocation of the Shoulder

## Report of a Case

BY S. L. WEISSMAN, M.D., AND G. TOROK, M.D., TEL-AVIV, ISRAEL

*From the Department of Orthopaedic Surgery, Tel-Hashomer Government Hospital, Tel-Aviv*

Posterior dislocations of the shoulder joint are extremely rare and, according to McLaughlin, represent only 3.8 per cent of all shoulder dislocations. The percentage must be still lower for the recurrent variety. Févre and Mialaret observed three posterior dislocations in a series of a hundred recurrent dislocations of the shoulder and a search of the literature disclosed only a few other instances.

Bilateral posterior dislocations, on the other hand, seem to be exceedingly rare. Arden found only four cases to add to the one he was reporting. All of them were acute and for the most part went undiagnosed for some time.

Only two reports of a bilateral recurrent posterior dislocation could be found in the available literature[2, 6]. For this reason, and because of the peculiarities of the clinical and pathological findings we thought it worth while to report the following example.

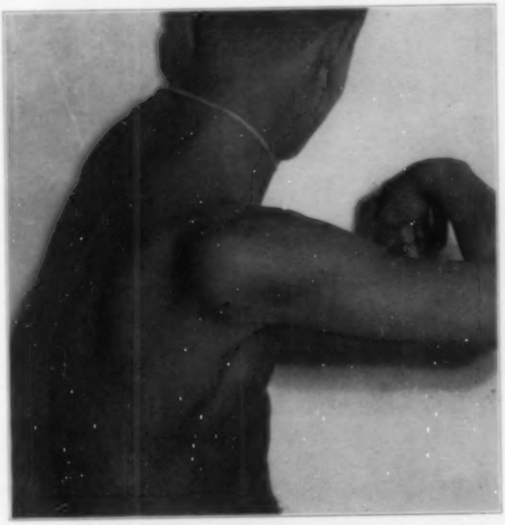

FIG. 1

Photograph of the right shoulder during dislocation. The prominence of the humeral head under the posterior part of the deltoid muscle is shown.

The patient, a healthy twenty-year-old male, was referred to the hospital because of marked instability of his right shoulder joint which dislocated each time he raised his arm. Although he could easily reduce the dislocation himself by twisting his arm, the patient was seriously handicapped in his work because of pain each time the dislocation occurred.

He became aware of this instability one month prior to his admission, a few days after he fell on his right arm. Nothing abnormal was detected at a medical examination at that time, but a few days later the shoulder began to dislocate upon movement. After a month the instability was correctly diagnosed and the patient was referred to the hospital.

The patient remembered having fallen on his right arm about half a year previously, after which his arm and shoulder were immobilized in a plaster-of-Paris cast. He removed the cast himself after four weeks and quickly recovered the use of his arm.

On admission he carried his right arm in a sling and was very reluctant to move it. Passive movements were free almost up to the horizontal. At that moment, when the arm was in about 90 degrees of forward flexion, internal rotation, and slight adduction, a click was heard and the shoulder dislocated posteriorly with the humeral head protruding underneath the posterior portion of the deltoid muscle (Fig. 1). Reduction was easily accomplished by extension, external rotation, and slight abduction of the arm. When persuaded to disregard his pain and to purposely reproduce the dislocation and the reduction, the patient accomplished both of them in the same manner.

Physical and laboratory examinations did not disclose any other abnormal findings.

Routine roentgenographic examination of the shoulder was negative. The same could be said about the

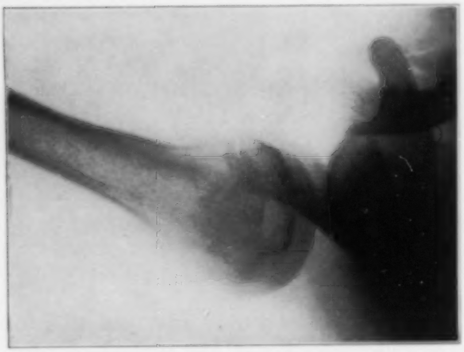

FIG. 2

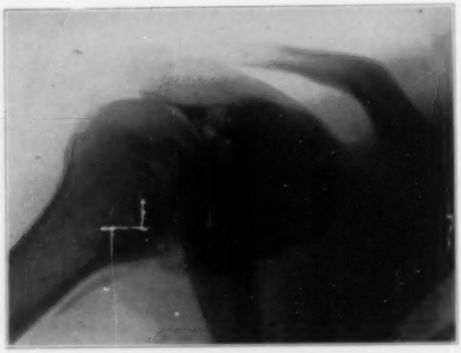

FIG. 3

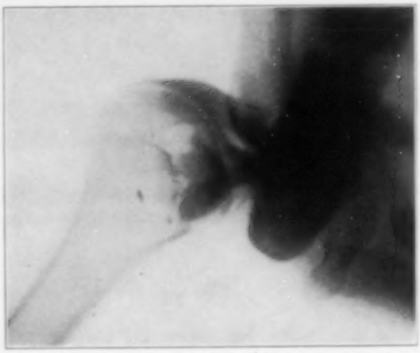

FIG. 4

Fig. 2: Vertical roentgenogram made during dislocation showing the subacromial displacement of the head.

Fig. 3: Arthrogram of the right shoulder. Anteroposterior view with the joint in normal position. There is a posterior pouch filled with contrast medium.

Fig. 4: Arthrogram of the right shoulder. Vertical view with the joint dislocated. The dislocation creates a kind of hourglass constriction between the head and part of the posterior pouch.

anteroposterior roentgenogram made with the shoulder dislocated. The posterior dislocation, subacromial in type, became apparent only in the vertical (axial) view (Fig. 2). Arthrography with contrast medium disclosed the existence of a posterior capsular pouch filled with contrast fluid (Figs. 3 and 4).

Operative repair was undertaken on March 1, 1956. With the patient in supine position, the shoulder was approached through a curved posterior incision. After reflection of the skin and fascia, the portion of the deltoid muscle which arises from the spine of the scapula was detached downward and laterally until the teres minor muscle was plainly visible. Both the infraspinatus and teres minor muscles were clearly defined, and the dissection was carried further between them in order to gain access to the posterior aspect of the joint capsule. Both these muscles were then sectioned vertically and reflected enough to expose the pouch formed by the distended capsule. When opened by a vertical incision running through the middle of the pouch, the interior of the joint disclosed a frayed and worn posterior labrum. No defect in the humeral head was found.

At that stage, the gliding of the head over the labrum and into the posterior pouch could be demonstrated by performing the same maneuvers as during the clinical examination; forward flexion, internal rotation, and slight adduction dislocated the head, whereas extension, external rotation, and slight abduction reduced the dislocation.

Repair was accomplished by suturing the lateral edge of the incised capsule to the posterior labrum and overlapping the medial edge over the posterior aspect of the capsule. Again the cut edges of the infraspinatus and teres minor muscles were sutured to each other with overlapping in order to strengthen the repair. These steps were performed with the arm held in external rotation. After closure of the wound, however, the arm was bandaged to the thorax in neutral rotation; the former position was considered too awkward for postoperative care.

The postoperative course was uneventful and the patient was discharged after a few days. The bandage was removed after four weeks and physical therapy consisting in active shoulder exercises was prescribed. After another six weeks he recovered a full range of active movements and resumed work.

The patient reported again about one month later complaining this time of instability in his left shoulder. Symptoms started about a week earlier after he fell on his left arm. The incident seemed quite trivial at the moment, but the symptoms and the signs found at the clinical and roentgenographic examinations were in all respects identical to the ones he experienced previously in his right shoulder.

The right shoulder was symptomless and functioned normally.

Surgical repair of the left shoulder was undertaken on July 5, 1956, the same procedure being used. There was but one different pathological finding. Besides the posterior changes, a tear of the anterior labrum was found on exploration of the joint cavity. Repair of this lesion however was not attempted and only the posterior Putti-Platt repair was carried out. Subsequent recovery was uneventful and complete (Fig. 5).

Since then the patient has not reported any further dislocations of either shoulder.

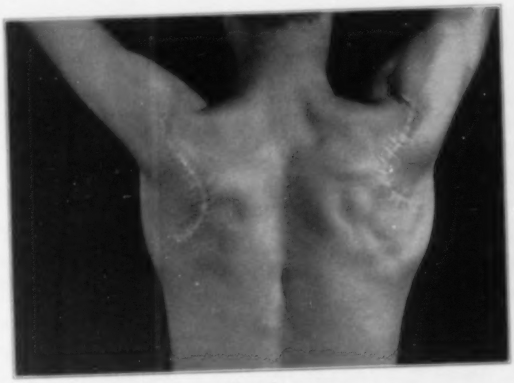

FIG. 5

Follow-up photograph showing range of motion.

## DISCUSSION

The relative ease of the diagnosis in our case is worth mentioning. Because of their infrequent occurrence and the failure of the standard anteroposterior roentgenograms to demonstrate the posterior displacement, diagnosis of posterior dislocation of the shoulder is often overlooked. This fact, which is mentioned in almost every published report, pertains mostly to the acute type of posterior dislocation. The recurrent type can be diagnosed far more easily provided the dislocation can be witnessed by a medical observer either accidentally or through voluntary reproduction by the patient.

In our case the posterior displacement of the head which became prominent under the posterior part of the deltoid muscle could not escape notice. This, in turn, prompted the making of vertical roentgenograms and led to the establishment of the correct diagnosis. However, even in so marked a case, it took some time until the patient found his way to the hospital.

Another point to be mentioned concerns the anatomicopathological findings. The presence of a pouchlike posterior distension of the capsule and a frayed posterior labrum can be easily explained by the mechanical action of the dislocating humeral head. Less easily explained is the presence of a torn anterior labrum in the left shoulder. The acute trauma, however small, may account for it, but why a torn anterior labrum should never have produced an anterior but a posterior dislocation remains unexplained.

The bilateral occurrence of the affection and the triviality of the trauma which induced the sequence of events may well point to the possibility of a congenital predisposing factor. A congenitally redundant posterior capsule may have been present before the initial trauma and thus may have favored the posterior gliding of the head. It would account for the short time in which the subsequent dislocations completed the formation of the posterior pouchlike distension of the capsule, as well as for the unusual instability of these joints.

A congenital predisposing factor could also account for the fact that with a torn anterior labrum the left shoulder still dislocated posteriorly. The redundant posterior capsule may have favored the gliding of the head under the acromion instead of under the coracoid process once the acute trauma had distended the joint space.

These explanations are, of course, entirely hypothetical and there is no evidence whatsoever to substantiate them.

The last point to be discussed is that of terminology. Möllerud applied Blumensaat's classification of patellar dislocation to the shoulder. Thus, the recurrent type of dislocation is one in which the dislocation occurs spontaneously at more or less frequent intervals as a result of a primary dislocation; however, in the "habitual" type, the joint is dislocated every time the shoulder is put in a determined position. As pointed out by Hindenach, both these types tend to become confused, and "following an original dislocation, the disability may recur every time the arm is abducted, or flexed and elevated. Such a condition, although recurrent, is also habitual."

This statement applies to our case. Although the exact nature of the initial injury cannot be ascertained because of lack of medical evidence, there is no doubt about its influence on the subsequent symptoms of the habitual type. Therefore no sharp distinction can be drawn and both terms can be used to designate the disability of our patient. The term *recurrent* has been chosen because of its prevalence in the literature.

Concerning the treatment, the posterior Putti-Platt procedure seems to have been of value in preventing further recurrences considering the previous severity of the affection, although the follow-up period must be considered too short to warrant definite conclusions.

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# A Modified Forearm Rotation Splint

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Effective use of forearm rotation splints which have been previously described[1,2] is notoriously difficult for two principal reasons: (1) inefficiency of the rotator mechanism and (2) insufficient fixation of the hand and wrist where the corrective force is applied.

This static splint has been found very effective in patients with cerebral palsy either to correct pronation contracture or to maintain the patient's hand in a functional position (Figs. 1 and 2). In patients with poliomyelitis, following surgical release of pronation contractures, it has adequately maintained the benefit obtained by successive physical therapy sessions.

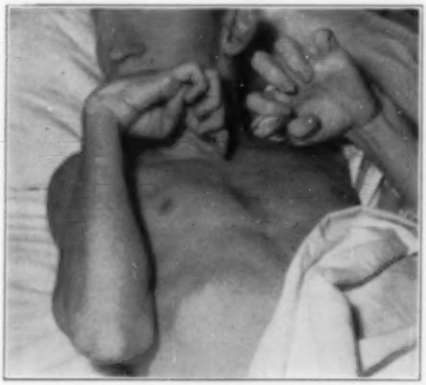

FIG. 1

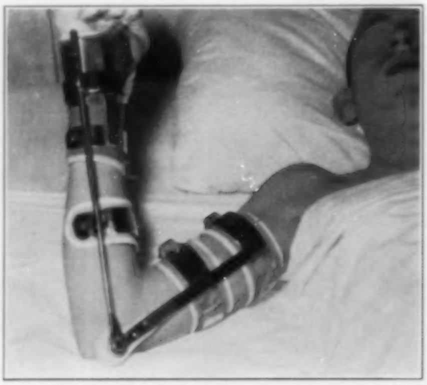

FIG. 2

It is felt that the rotator force should act primarily at the carpal area and at the bases of the metacarpals. When a simple band across the palm is used, a deformity of the hand results, caused by rotation of the metacarpals. This rotation also dissipates part of the corrective force.

The supinator splint described by Funsten is only a thin metal band across the palm. The modified form[3] results in a better fixation of the hand, but the rotation is accomplished with difficulty. Bunnell's splint has good rotator action, but it is cumbersome and does not adequately support or immobilize the hand and wrist.

A splint has been devised in an attempt to overcome these difficulties. It is constructed as follows: A plaster mold of the extremity is made with the elbow flexed at 90 degrees and the forearm and hand in as corrected a position as possible; it is important to include the proximal phalanx of the thumb in the mold (Fig. 3).

A leather lacer is made to fit the hand, wrist, and the distal third of the forearm (Figs. 5 and 6). To this is attached a metal piece (soft 16-gauge aluminum) which conforms to the base of the hand, the wrist, and, approximately, the distal two centimeters of the forearm. It extends laterally to the radial border; medially it surrounds the ulnar border and a third of the dorsum of the hand, the wrist, and the distal third of the forearm. At the proximal end of the lacer an inch-wide band is added, attached to the hand piece by a strip of stainless steel, one-half by one-eighth of an inch. The arm segment is also made of one-half by one-eighth of an inch stainless-steel strips. Two arm bands with adequate straps and padding are fitted to hold it in place. At the elbow, there is a free-

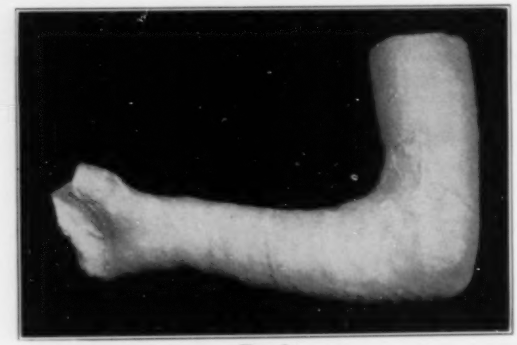

FIG. 3

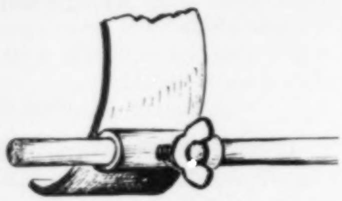

FIG 4

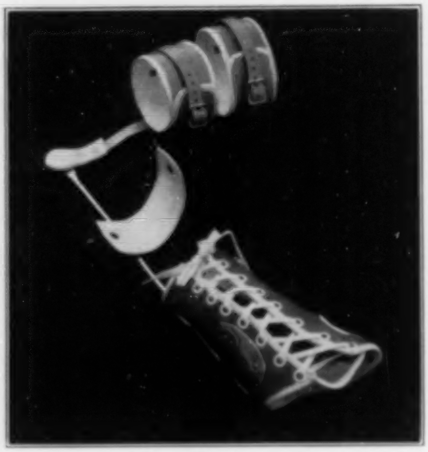

FIG. 5

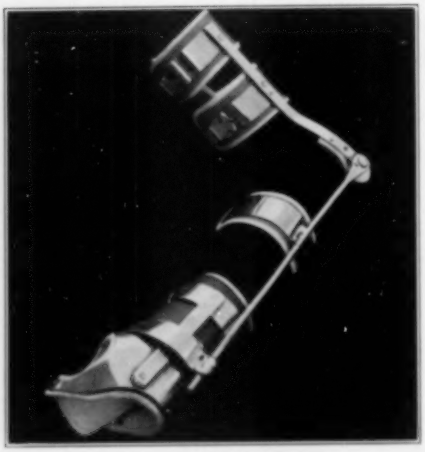

FIG. 6

motion joint with flexion to at least 40 degrees, in order to allow the patient to bring his hand to his mouth. In some instances, the joint extension must be blocked at 155 degrees; otherwise, the splint loses its efficiency because the arm piece rotates with the forearm when the elbow is extended to 180 degrees.

The forearm shaft is a one-quarter inch cold-rolled rod of stainless steel. In some instances, it may be necessary to place an inch-wide half-band at the junction of the middle and upper thirds of the arm in order to prevent the arm segment from sagging when the elbow is flexed at 90 degrees or more.

The hand piece is connected to the forearm rod by a swivel joint (Fig. 4). It is made by attaching to the hand piece a one and one-quarter inch length of tube which fits over the forearm rod. A butterfly or set screw in the tube tightens down on the rod to permit fixation in the desired position. The swivel joint is placed over the distal end of the ulna where it is nearest to the rotation axis of the forearm. The patient's forearm and hand can then be made to pronate or supinate, rolling around the swivel joint. The forearm rod may need bending in order to conform better to the contour of the patient's forearm.

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# Hand Drill or Wire Inserter

BY HAROLD LUSSKIN, M.D., LILLIAN S. LUSSKIN, M.D., AND
RALPH LUSSKIN, M.D., NEW YORK, N. Y.

We have always found it difficult in doing hand surgery to control the hand while someone else uses the drill or the assistant has to hold the hand and the surgeon uses the drill. In either case, complete control is not present and, occasionally, unnecessary drilling is done before a Kirschner wire can be put through the metacarpals. Frequently, the wire will slip while one tries to drill the bone. All drills require the use of two hands. It was this which made us bring the problem to the manufacturer and between us we worked out the drill to be described.

The drill is a reciprocating instrument, worked on the principle of the Yankee screwdriver. A strong spring bent in the form of a looped U, like a very large safety pin with the point and head cut away, is used. By grasping this spring and compressing it between the fingers and the palm of the hand, and then releasing it, the spring can be made to move back and forth. One end of the spring is fastened to a chaneled shaft which is stable at its base. The other end slides over the shaft, which is made to rotate within that base. Grooves in the shaft allow a pin, running in these grooves, to rotate the shaft through about 300 degrees. At the end of the shaft is a chaneled chuck, which can hold a full-length Kirschner wire or a small fluted drill. In essence, this is the instrument.

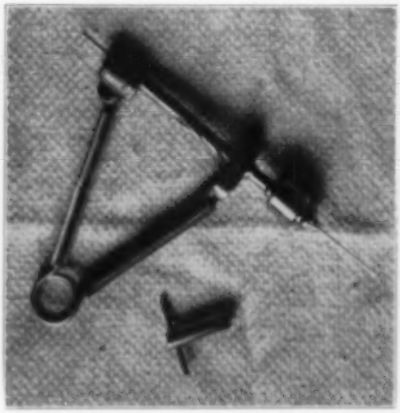


FIG. 1

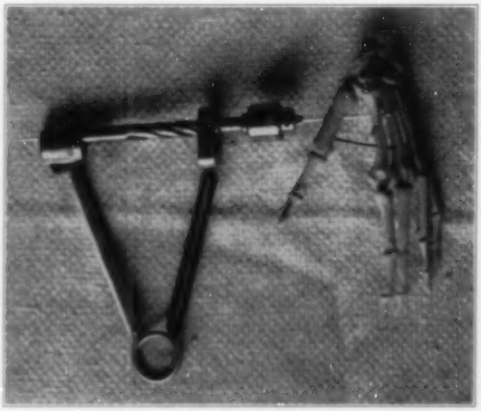


FIG. 2

By pressing the point of the wire, or the drill, against the bone, it is possible to bore a hole in the bone, if it is a small one, using one hand to work the drill and one hand to hold the bone. We have tried it purposely on heavy bone and it works quite well, although strength is needed. Of course it will not work on a femur or the cortical part of the tibia; but it will work on the carpal bones, the metacarpal bones, and the tarsal bones.

Figure 1 is a photograph of the instrument with a full-length Kirschner wire. Figure 2 shows the drill with the Kirschner wire and the skeleton of a hand. The instrument can be improved considerably by using the same mechanism as in the Yankee screwdriver, so that it can be made to hold a small screwdriver, rotating in one direction, of course not continuously, or the other direction, by adjusting a rachet reverse.

# The Step-Down Bit in Screw Fixation of Fractures

BY THOMAS D. HALL, M.D., CHICAGO, ILLINOIS

*From the Orthopaedic Department, Northwestern University Medical School, Chicago*

Any consideration of the value of a step-down drill bit as illustrated in Figure 1 must be predicated on a knowledge of the basic fundamentals of screw fixation in the treatment of fractures. These principles, which are an adaptation from the art of woodcraft, are well appreciated and utilized by most orthopaedic surgeons today.

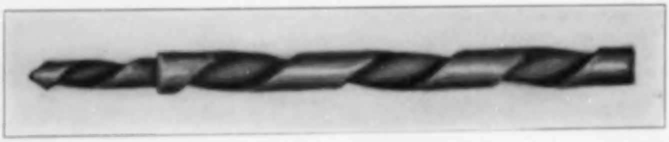


Fig. 1

Figure 2-A illustrates the dual cortex fixation, which is advantageous in the application of a plate across the fracture site and when the screw does not traverse the fracture. Dual cortex fixation approximately doubles the number of threads of the screw engaged in the cortical bone and, consequently, has a proportionate effect on the stability of the plate approximation to the bone. In the event that the fracture is traversed, the principles illustrated in Figure 2-D should be considered.

Figure 2-B illustrates the dual cortex fixation of the screw which does traverse the fracture. It is obvious that engagement in the first cortex (*B-1*) is of no value in maintaining the stability of the operative fixation of the fracture. In the event that purchase is lost at the site of engagement in the second cortex (*B-2*), the fragments will separate. Fixation of the screw threads in both cortices produces a fixed relationship between the fragments and approximation of the second fragment is impossible. Adversely, any delay in engagement of the screw in the cortex of the second fragment will cause distraction with progress of the threads through the initial cortex; engagement of the screw will then result in a fixed position of distraction.

Figure 2-C illustrates the lag-screw principle. Because of the absence of threads at the head end of the screw shaft, no purchase is present in the cortex of the first fragment (*C-1*), and progress of the screw threads through the second fragment (*C-2*) results in an approximating force. This type of fixation with approximation, although ideal, requires

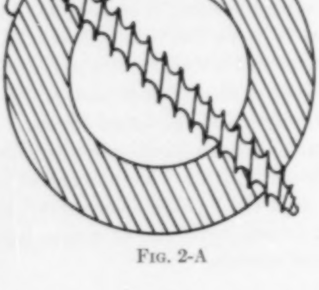


Fig. 2-A

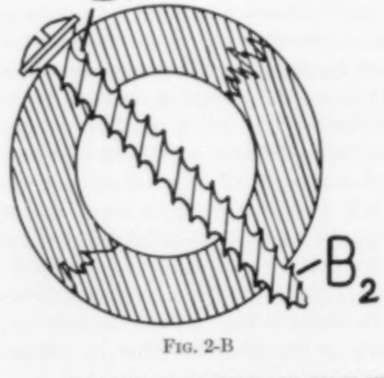


Fig. 2-B

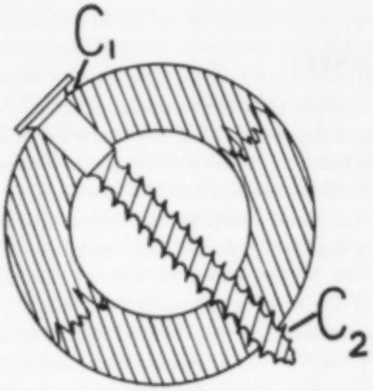


FIG. 2-C

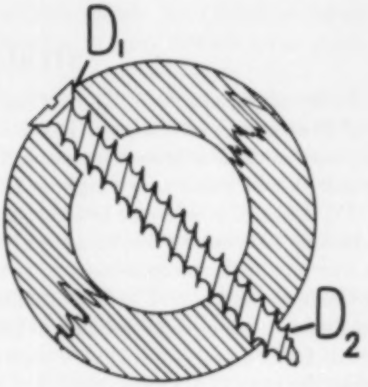


FIG. 2-D

stocking lag screws in many sizes in already overcrowded orthopaedic cabinets.

Figure 2-D illustrates the technique which most orthopaedic surgeons use to incorporate the lag-screw principle in the use of the standard screw permitting approximation of the fragments. The screw channel is first drilled with a $\frac{7}{64}$-inch drill bit which permits engagement of the threads in the bone. Prior to insertion of the screw, the drill hole in the first cortex (*D-1*) is expanded by use of a $\frac{9}{64}$-inch drill bit to eliminate purchase of the screw threads at this site, and approximation of the fragments occurs with progress of the screw threads through the second cortex (*D-2*).

The step-down drill bit has a $\frac{9}{64}$-inch drill at its base and is stepped down to a $\frac{7}{64}$-inch bit in the distal three-eighths or one-half inch. It possesses the following advantages:

1. It eliminates the necessity for utilizing two drills and two bits. In less affluent institutions in which only one drill is available, it eliminates the necessity of changing bits.
2. Both drill holes of different sizes are made in one operative step.
3. On occasion, expansion of the $\frac{7}{64}$-inch drill hole in the first cortex may be produced by the insertion of the $\frac{9}{64}$-inch bit in a different direction, and the subsequent insertion of the screw may miss the hole in the second cortex. This is eliminated by the step-down drill.
4. Penetration of adjacent soft tissue upon completion of drilling in the second cortex is limited to the length of the $\frac{7}{64}$-inch portion of the drill minus the width of the cortex due to the abutment of the thicker portion of the drill on the smaller drill hole.

# STERLING BUNNELL

In the appreciations of Dr. Sterling Bunnell's career that have appeared in *The Journal of Bone and Joint Surgery* (December 1957 and January 1958), his contributions to Army medicine have been mentioned. These contributions deserve fuller public acknowledgment, for he stands very high on the Army Medical Service's roll of honor.

Dr. Bunnell's influence on Army medicine was most conspicuous during and after World War II when he served as one of The Surgeon General's civilian consultants, but this was not his first connection with the Army. In World War I he had a brief career as a medical officer, and in fact obtained part of his medical education at the Army's Neurological School, established in Philadelphia shortly after the United States entered the war. Later he served in France with Base Hospital No. 47 as Chief of Surgical Service, holding the rank of Captain, Medical Corps. This hospital, located at Beaune in the Côte d'Or, opened on September 1, 1918, and continued operations until January 23, 1919. Dr. Bunnell left the service in the following March. It was during his tour as an Army officer that he published an article on tendon surgery in *Surgery, Gynecology and Obstertics* (January 1918). His experience with the wounded no doubt helped to guide him toward specialization in hand surgery. It was in this field that he was soon to achieve an international reputation; for he became an authority as a hand surgeon before the outbreak of World War II.

During my tour of duty at Letterman General Hospital in San Francisco, from 1936 through 1940, I was most fortunate to get to know the Bunnells—Sterling, Mrs. Bunnell, and Sterling, Jr.

While inspecting Valley Forge General Hospital, a plastic-surgery center, in the fall of 1944, I was shocked to see many "crippled hand" cases. It appeared that not enough was being done for them. Immediately I thought of Sterling Bunnell as the man to head a "crippled hand" service for the Medical Corps of the Army.

At once I wrote him a personal letter outlining the problem and asking his help as a Civilian Consultant. His response was immediate in that he would close his office and come to Washington. This he did and his office remained closed for two years.

He was appointed a Civilian Consultant to the Secretary of War—"to guide, integrate and develop the special field of hand surgery"—in the Army. The Surgical Division of the office of The Surgeon General assisted him in carrying out his mission.

Dr. Bunnell entered upon these duties on November 29, 1944. His great treatise *Surgery of the Hand* was published at almost the same time; the Army adopted it as an official text and distributed the book to all its hospitals.

In the month following his appointment Dr. Bunnell made the first of a long series of visits to Army hospitals in the United States. His impression of the treatment of hand injuries was not favorable. He found "too many cases" in which improper traction, splinting, and skin-grafting resulted in less complete restorations of function than he considered possible. His prescription, which he reiterated from then on and directed all his effort toward carrying out, was to improve the quality of treatment by bringing together specialists in orthopaedic surgery, plastic surgery, and neurosurgery to work on injured hands and to qualify as many of them as possible in all three specialties. "It is impossible," he wrote, "to have three specialists work together or in series on a hand. The officers selected to do hand surgery should be able to do plastic, neurosurgical and other orthopedic surgery. . . . This is forcefully necessary in hands due to the small size and to the fact that in this small space the three specialties are intimately interwoven. The only possible division would be to have the primary pedicle skin flap applied by a plastic specialist though this has its drawbacks and, of course, is not too difficult for anyone able to reconstruct hands." His ideal of a three-ply surgeon was not always attainable, since few surgeons were qualified in all three fields. As a corollary to concentration of surgical talent he advocated concentration of complicated hand cases in a special service, preferably on a par with the other major services of a hospital.

Some progress in these directions had been made before Dr. Bunnell took charge. During the preceding year and a half the policy of concentrating a number of specialists in particular branches at certain general hospitals and channeling appropriate patients to them had been instituted and broadened. By August 1944, eight of the general hospitals had been designated as centers for plastic surgery, including treatment of the hand; in February 1945 a ninth center was added. In a few centers hand cases had been segregated in special wards or were under the care of a special group of surgeons.

Much, however, remained to be done. Many patients with crippled hands were still scattered outside the centers. There was a dearth of surgeons qualified to treat difficult cases, and some of the most competent were not placed where they could do the most good. Dr. Bunnell's wide knowledge of the talent in his field enabled him to suggest where such talent could be found and best utilized. He carried his campaign for improved treatment directly into the hospitals. In the course of eight tours between December 1944 and February 1947, each of which lasted about a month, he visited almost all the general hospitals in the United States. There he conducted no less than twenty-three courses of three or four days each, giving operative demonstrations as part of the course. At each hospital he also "surveyed the problems and procedures of hand surgery, evaluated the qualifications of medical officers assigned to this work, and gave active consultation in individual cases. . . . These visits, and the reports to The Surgeon General which followed, resulted in great stimulation of interest in the problems of hand surgery, in improved management policies at the various hospitals, and in a wide diffusion of technical knowledge among the officers concerned." At the same time Dr. Bunnell encouraged the formation of a closely knit hand-surgery unit in each hospital receiving hand patients in appreciable numbers. Such a unit constituted a separate service, or functioned under the orthopaedic or plastic section of the hospital. It has been estimated that during the entire course of the war at least 22,000 injured hands were treated in the hospitals of the Zone of the Interior.

As already indicated, Dr. Bunnell's services to the Army did not end with the war. As long as a considerable number of war injured remained in Army hospitals he continued his rounds. In 1946, he was awarded the Presidential Medal for Merit "in recognition of exceptionally meritorious conduct in the performance of outstanding services as Civilian Consultant, Surgical Consultants Division, Office of The Surgeon General." When his visits ceased in 1947, he accepted an appointment as a teaching consultant in hand surgery at Letterman Army Hospital, San Francisco, where his advice and instruction, carried on in conjunction with his private practice, proved as valuable and stimulating as in a wider sphere. He found time also to serve as consultant to the Navy Hospital at Oakland.

Meanwhile, the Army Medical Service requested Dr. Bunnell's aid in producing a volume on hand surgery for its history of the Medical Department in World War II. He willingly agreed, and, when the volume appeared in 1955, it bore his name as Editor and included a long chapter on general practice written by himself. The book received favorable comment in professional journals; one reviewer remarked that Dr. Bunnell's chapter "represents one of the most complete, concise, and simple descriptions of the treatment of the injured hand to appear in publication."

Dr. Bunnell died on August 22, 1957, at the age of seventy-five, while still a consultant to Letterman Army Hospital. The Army's indebtedness to him may be summed up by an extract from the citation which accompanied his Medal for Merit. ". . . His tours of duty were made at heavy personal sacrifice and without regard to his own interests. The result was the achievement of functional results in surgery of the hand hitherto believed beyond attainment.

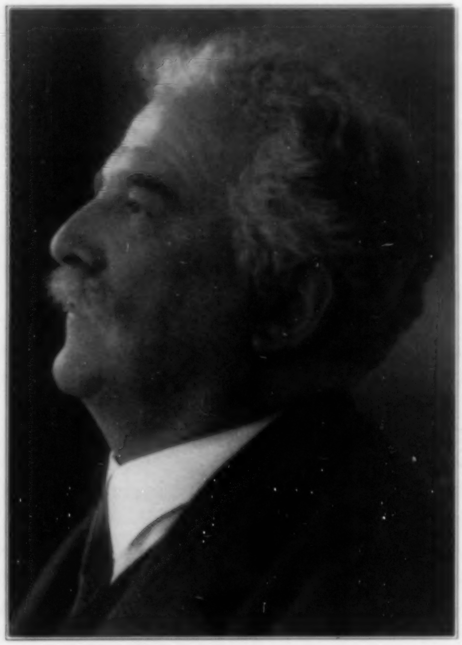
"Wounded soldiers who have been discharged from Army hospitals with unimpaired hand functions, mutilated soldiers who have functional hands which once would have been useless, owe Dr. Bunnell a heavy debt of gratitude, as do the Army surgeons who were taught by him and who will carry back into civilian practice the lessons which they learned from him and which they will apply for the benefit of all with similar injuries."

NORMAN T. KIRK, *Major General*
*The Surgeon General, U.S.A., Retd.*

## AUSTRIAN ORTHOPEDIC SOCIETY

During the past year Austria lost two of her pioneers in orthopaedic surgery, known the world over; both were eighty-four years of age.

HOFRAT PROF. DR. HANS SPITZY was, in 1915, in the *orthopädisches Spital* in Vienna where he worked out a program of what is now known as rehabilitation. His principal work was with children. He wrote thirteen books and published about 200 scientific papers. Only two years ago his pupils honored him with a book *Lehrbuch der praktischen Orthopädie*.



**Hofrat Prof. Dr. Hans Spitzy**

**Prof. Dr. Arnold Wittek**

PROF. DR. ARNOLD WITTEK founded the orthopaedic hospital in Graz (1914) for the rehabilitation of war wounded and men disabled from industrial accidents. Furthermore, he initiated the building of a heliotherapeutic center at Stolzalpe for the bone and joint tuberculous and a rehabilitation center for crippled children in Graz. Prof. Wittek's papers cover all the fields of orthopaedic surgery.

Last year the annual joint meeting with the Society of Traumatology and the Society of Physical Medicine was held at Bad Ischl: problems of operative treatment of the congenital dislocation of the hip, spastic hemiplegia, defects of skin following injuries and other traumatological problems were discussed. Two motion picture films were shown: one showing transplantation of the ulnar nerve following chronic paralgia and one of the method of treatment of recent severe fracture of the calcaneus.

In a special meeting Dr. W. P. Blount of Milwaukee spoke on epiphysiodesis and the Milwaukee brace.

Prof. Erlacher was elected president for 1957.

*Prof. Dr. W. Ehalt*

**LAWSON THORNTON, M.D.**
**1885-1957**

Dr. Thornton was born December 7, 1885, in Talladega, Alabama. His college work was at the Alabama Polytechnic Institute and he graduated from Johns Hopkins University School of Medicine. After finishing the internship, he returned to Talladega to practice medicine in 1912. He and Miss Leila Dumas of Mobile were married on April 29, 1913. With his bride, he soon moved to Birmingham and continued to practice medicine and surgery until he entered the Army in 1917. There he became interested in orthopaedic surgery and while in the Army at Fort McPherson, he met and admired Dr. Michael Hoke. He was soon fascinated with the type of work that Dr. Hoke was doing. After his discharge, he went to Dr. Hoke, and that great technician and the deep, kindly and humble, younger man, dedicated to orthopaedic surgery, became associates. The Scottish Rite Hospital for Crippled Children was an early result of their teamwork. Their reputation was not only professional. Just as or even more fruitful was the admiration and love of many children and their families. Children who had come in crawling were able to stand upright and thank the tall, soft-spoken man, with tears in their eyes.

Dr. Thornton gave much to orthopaedic surgery, he spoke modestly and at times with some embarrassment, yet his presentations, telling of good and rewarding work were well regarded. He was early recognized by his colleagues and was a member of The American Orthopaedic Association, The American Academy of

Orthopaedic Surgeons, the Sir Robert Jones Club, and he was a diplomate of the American Board of Orthopaedic Surgery. His professional attainments are known and stand on their merit.

No one stood in awe of Lawson Thornton. He, with kindness, modesty, and humility soon became a part of you and your problems, whether you were a patient or a doctor. While we recall the professional skill of Dr. Thornton, we remember him as a fine, quiet gentleman who was often seen riding horseback, teaching his daughter Anne, and happy in her pleasure and progress. Lawson will neither be replaced nor forgotten.

His death occurred, following a rather depressing period of illness, on June 26, 1957 in Atlanta, Georgia. Mrs. Thornton and daughter Anne of Atlanta and his sister, Miss Eugenia Thornton of Talladega survive him.

*F. W. McR.*

## DeFOREST PORTER WILLARD, M.D.

### 1884-1957

On October 3, 1957, The American Orthopaedic Association lost one of its oldest and most esteemed members, Dr. DeForest Porter Willard, who died at Brunswick, Georgia.

Born in Philadelphia, Pennsylvania, in 1884, the son of Dr. DeForest Willard and Elizabeth Porter Willard, he received his early education at the Penn Charter School in Philadelphia. He graduated with a degree of B.S. from the University of Pennsylvania in 1905, and received a degree of M.D. from the Medical School of the University of Pennsylvania in 1908. After internship at the University of Pennsylvania Hospital and Mayo Clinic, Dr. Willard entered the practice of medicine in Philadelphia in 1911.

Dr. Willard quite naturally turned to orthopaedic surgery as his life work, for his father, the late Dr. DeForest Willard, had established the orthopaedic department at the Medical School of the University of Pennsylvania and was the first professor of orthopaedic surgery. In 1912, Dr. Willard was appointed Assistant in Orthopaedic Surgery at the University of Pennsylvania and Philadelphia Orthopaedic Hospitals and served in this capacity until 1917.

In April 1917, having been commissioned a First Lieutenant in the Reserve Corps of the United States Army, he accompanied Dr. Joel E. Goldthwait to England with the first contingent of orthopaedic surgeons who volunteered to serve with the British Army prior to the formation of the American Expeditionary Forces. He served with the Royal Army Medical Corps at the Military Orthopaedic Hospital, Shepherds Bush, London, and St. Catherine's Lodge, Regents Park (British Red Cross), from April 1917 to December 12, 1917, when he was ordered to France as orthopaedic consultant to the 42nd Division of the American Expeditionary Forces, with the rank of Captain. After three months of service as consultant to the 42nd Division, Dr. Willard served with Evacuation Hospital No. 1 at Toul, France, at the Vichy Hospital Center, and at General Headquarters, Tours, France. In 1919 he was honorably discharged from the Army with the rank of Major. In 1925 he was made a Lieutenant Colonel in the Medical Reserve Corps, United States Army.

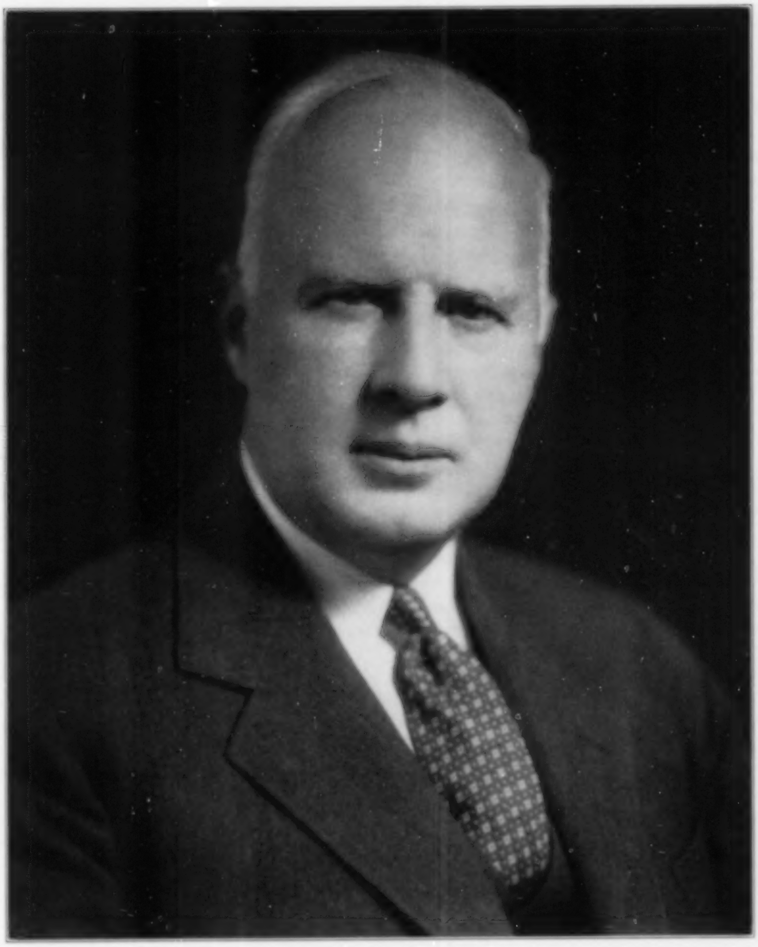
Upon his return to Philadelphia, Dr. Willard engaged in the practice of orthopaedic surgery, and in 1920 was made Professor of Orthopaedic Surgery and Vice-Dean of Orthopaedics at the University of Pennsylvania Graduate School of Medicine, a position he held until his retirement from practice in 1951.

Dr. Willard was orthopaedic surgeon to the Shriners' Hospital in Philadelphia from 1925 to 1927, and consulting orthopaedic surgeon to Pennsylvania, Bryn Mawr, Chestnut Hill, and other hospitals in Philadelphia, and the Babies Hospital in Wilmington, Delaware, until his retirement.

Dr. Willard served as Secretary of The American Orthopaedic Association from 1921 to 1931, and was elected President of the Association for the year 1934 to 1935. Dr. Willard was also a member of The American Academy of Orthopaedic Surgeons, American Surgical Association, Philadelphia Academy of Surgery, Philadelphia College of Physicians, and other county, state, and national medical societies.

In 1926, Dr. Willard married Margaretta Miller of Wilmington, Delaware. She was a close and stimulating companion until his death, as she was deeply interested in his medical career and shared with him his love for fly-fishing and golf. This harmony of interests eased the burden of Dr. Willard's busy professional life and enabled them to pass many happy weeks "whipping" the waters of Canada for trout and salmon and to spend many delightful hours on the golf course. In both these sports Dr. Willard excelled.

While the author of a number of articles in medical and surgical journals, Dr. Willard was not a volumi-



DeFOREST PORTER WILLARD

nous writer. What he wrote, however, based on personal experience and keen observation, was always sound and clearly expressed, but with a definite leaning toward conservatism. His most valuable contribution to orthopaedic surgery was the impress which he left on the scores of young men who came under his influence as a teacher in the postgraduate school of the University of Pennsylvania. His kindly manner and helpful attitude, his integrity which shone clearly throughout his life, and his devotion to sound and established surgical principles in his teaching have left a deep impression on orthopaedic surgery which will be felt for years to come—an enduring memorial to his life.

*F. D. D.*

# News Notes

A plan of joint action aimed at preventing accidents and improving care of accident victims was announced by the **American College of Surgeons,** the **National Safety Council,** and the **American Association for the Surgery of Trauma.**

As outlined by the representatives of the three participating organizations, the Program will include:

1. Public education in accident prevention and handling of the injured;
2. Employment of joint state and local committees of the American College of Surgeons and National Safety Councils, together with other interested surgeons, safety engineers, and public officials to formulate safety plans for local communities;
3. Possible registration of unusual cases of injury;
4. Proposed investigations of emergency care of traffic injuries;
5. Model legislation to require adequate training in first aid and transportation of the injured for ambulance attendants, policemen, and firemen;
6. Cooperation in the production and improvement of training materials and instructional aids dealing with problems in handling the injured.

Resources of the three organizations will be used in the effort to advise and assist civic groups to obtain passage of local ordinances requiring adequate training in handling of the injured by ambulance attendants, policemen and firemen, the joint statement said. Under a proposed model ordinance, ambulance attendants are required to have completed standard and advanced first aid training and additional training as recommended by local health departments, to carry cards indicating their qualifications and to be re-examined and certified annually for their fitness to serve.

Cities named as having such ordinances now were San Francisco; Minneapolis; Syracuse, New York; Cincinnati; Philadelphia; Flint, Michigan; Kansas City, Missouri; and Butte, Montana.

A Joint Policy Committee has been appointed composed of representatives of the three participating organizations to conduct the joint action program:

Representing the American College of Surgeons: I. S. Ravdin, M.D., *Chairman of the Board of Regents;* William L. Estes, Jr., M.D., Bethlehem, Pennsylvania, *President;* Preston A. Wade, M.D., New York, *Chairman of the Committee on Trauma,* and Paul R. Hawley, M.D., Chicago, *Director of the College.*

Representing the American Association for the Surgery of Trauma: Charles G. Johnson, M.D., Detroit, *Past-President;* Warren H. Cole, M.D., Chicago, a member of the Association's council; Dr. Estes and Dr. Wade.

Representing the National Safety Council: Lowell B. Fisher, Urbana, Illinois, *Vice-President for Schools and Colleges;* Walter K. Koch, Denver, *Vice-President for State and Local Safety Organizations;* George M. Wheatley, M.D., New York, *Vice-President for Homes;* and General George C. Stewart, Chicago, *Executive Vice-President.*

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## ORTHOPAEDIC ASSOCIATIONS OF THE ENGLISH-SPEAKING WORLD

Joint Meeting of the Orthopaedic Associations of the English-Speaking World, Shoreham Hotel, Washington, D. C., May 11th to 16th, 1958. Registration opens at 10:00 A.M. at the Shoreham Hotel, Sunday, May 11th, 1958.

Monday, May 12

Afternoon Session:

*Chairman:* President of The British Orthopaedic Association, Mr. Norman Capener

### Symposium on Orthopaedic Problems in Children

Opening remarks of the Chairman: Mr. Norman Capener.
Infantile Structural Scoliosis.
  J. I. P. James, Edinburgh, Scotland;
  G. C. Lloyd-Roberts, London, England.
Congenital Pseudarthrosis of the Tibia.
  H. B. Boyd, Memphis, Tennessee;
  F. P. Sage, Memphis, Tennessee.
Congenital Absence of the Fibula.
  C. A. Laurin, Toronto, Canada;
  A. W. Farmer, Toronto, Canada.

Paraplegia in Children.
P. L. Norton, Boston, Massachusetts;
J. J. Foley, Boston, Massachusetts.
Epiphyseal Stapling.
W. P. Blount, Milwaukee, Wisconsin.
Congenital Muscular Torticollis.
G. J. Garceau, Indianapolis, Indiana;
W. L. Franklin, Indianapolis, Indiana.

Tuesday, May 13

*Chairman:* President of the South African Orthopaedic Association, Dr. A. J. Helfet.

## Symposium on Arthritis

Morning Session:
Opening remarks of the Chairman: Dr. A. J. Helfet. Welcome for the National Institutes of Health: Dr. Joseph E. Smadel, Associate Director of the National Institutes of Health.
Factors Which Predispose to Osteo-arthritis.
Leon Sokoloff, National Institutes of Health, Washington, D. C.
Hemiarthroplasty of the Knee Using a Space Occupying Prosthesis for Painful Varus and Valgus Deformity.
D. L. McIntoch, Toronto, Canada.
Mold Arthroplasty of the Knee.
O. E. Aufranc, Boston, Massachusetts;
W. N. Jones, Boston, Massachusetts.
Attrition Ruptures of Tendons in the Rheumatoid Hand and Wrist.
O. J. Vaughan-Jackson, Kent, England.
Surgical Treatment of Rheumatoid Deformities of the Hand.
D. C. Riordan, New Orleans, Louisiana;
S. B. Fowler, Nashville, Tennessee.
Rehabilitation of the Hand in Rheumatoid Arthritis.
J. G. Kuhns, Boston, Massachusetts.
Spinal Osteotomy.
W. A. Law, London, England.
Hazards of Steroid Therapy.
Joseph J. Bunim, National Institutes of Health, Washington, D. C.
Afternoon Session:
Tour of the National Institutes of Health.
Tour of Tissue Bank, United States Naval Hospital of the National Naval Medical Center, Bethesda, Maryland.
Tour of Orthopaedic Wards, United States Naval Hospital of the National Naval Medical Center, Bethesda, Maryland.
Audio-Visual Program, Shoreham Hotel.

Wednesday, May 14

Morning Session:
*Chairman:* President of The Canadian Orthopaedic Association, Dr. G. W. Armstrong.

## Symposium on Fractures

Opening remarks of the Chairman: Dr. G. W. Armstrong.
The Blood Supply of Tubular and Cancellous Bone.
Ian Macnab, Toronto, Canada.
Non-union of Fractures of Long Bones.
Edwin F. Cave, Boston, Massachusetts.
Delayed Reduction of Fractures.
J. R. Moore, Philadelphia, Pennsylvania;
A. F. Seifer, Philadelphia, Pennsylvania;
J. W. Lachman, Philadelphia, Pennsylvania;
H. H. Steel, Philadelphia, Pennsylvania.
Central Dislocation of the Hip.
G. F. Pennal, Toronto, Canada.

Cervical Spine Injuries. Entities and Indications for Fusion.
J. N. Garber, Indianapolis, Indiana.
The Luschka Joints of the Cervical Spine. Anatomy, Physiology, and Pathology.
E. L. Compere, Chicago, Illinois.
The Stored Homograft. Experimental Data and Clinical Implications.
G. W. Hyatt, National Naval Medical Center, Bethesda, Maryland.

Afternoon Session:

**Symposium on Surgical Implants in Modern Surgery**

*Co-Chairmen:* Mr. Norman Capener, Exeter, England.
Dr. Joseph S. Barr, Boston, Massachusetts.
Members of Panel: (to be announced).
Audio-Visual Program, Shoreham Hotel.

Thursday, May 15
Walter Reed Army Medical Center

Morning Session:

Co-Chairmen: President of The Australian Orthopaedic Association, Dr. John Colquhoun.
President of New Zealand Orthopaedic Association, Dr. H. W. Fitzgerald.

**Symposium on Bone Tumors**

Opening remarks of the Chairmen: Dr. John Colquhoun.
Dr. H. W. Fitzgerald.
The Development of the Histological Classification of Malignant Bone Tumours.
H. A. Sissons, London, England.
Diagnosis and Treatment of Secondary Chondrosarcoma.
Roland Barnes, Glasgow, Scotland.
Surgical Treatment of Bone Sarcomata.
M. S. Thompson, Col. M.C., Walter Reed Army Medical Center;
S. J. Ritchey, Col. M.C., Walter Reed Army Medical Center;
T. B. Horan, Capt., M.C., Walter Reed Army Medical Center;
G. T. Baker, Capt., M.C., Walter Reed Army Medical Center.
Recent Experiences With Treatment of Osteogenic Sarcomata.
W. T. Green, Boston, Massachusetts.
Local Excision of Bone Tumours and Prosthetic Replacement.
H. Jackson Burrows, London, England;
J. T. Scales, Middlesex, England.
Orthopaedic Aspects of Myelomatosis.
D. Lloyd Griffiths, Manchester, England.
Parosteal Osteoma of Bone. Treatment.
M. M. Copeland, Washington, D. C.;
C. F. Geschickter, Washington, D. C.
Lunch at the Walter Reed Army Medical Center.

Afternoon Session:

General Biological and Field Theory of Bone Tumors.
Lent Johnson, Armed Forces Institute of Pathology.
Tour of Armed Forces Institute of Pathology.
Tour of Walter Reed Army Hospital and Orthopaedic Wards.
Tour of Army Prosthesis Research Laboratory, Forest Glen, Maryland.
Color Television Presentation, Post Theater, Walter Reed Army Medical Center.
Audio-Visual Program, Shoreham Hotel.

Friday, May 16
Shoreham Hotel

*Chairman:* President of The American Orthopaedic Association, Dr. George O. Eaton.

Morning Session:

Opening remarks of the Chairman: Dr. George O. Eaton.
Lumbosacral Interbody Fusion.
G. F. Dommisse, Pretoria, South Africa.

The Organization of the Components of Connective-Tissue Matrices That Normally Calcify.
R. A. Robinson, Baltimore, Maryland.
The Relation Between Molecular Ultrastructure and the Property of Calcificability of Bone.
Melvin Glimcher, Boston, Massachusetts.
The Anatomy of Bone Cysts.
Robert Kindred, Charlottesville, Virginia;
Lent Johnson, Armed Forces Institute of Pathology, Washington, D. C.
Rheumatoid Synovial Cyst of the Hip.
M. B. Coventry, Rochester, Minnesota;
H. F. Polley, Rochester, Minnesota;
A. D. Weiner, Rochester, Minnesota.
The Bone Changes in Sickle-Cell Anaemia and Its Genetic Variants.
J. S. R. Golding, Jamaica, British West Indies;
J. McIver, Jamaica, British West Indies;
L. Went, Jamaica, British West Indies.

Evening functions, in addition to other events, will include dancing, movies, and receptions by The American Orthopaedic Association and The Canadian Orthopaedic Association, as well as the traditional Banquet.

It is urged that all persons planning on attending the Meeting write promptly to the Shoreham Hotel, Washington, D. C., requesting room reservations.

## SCHEDULE OF ACTIVITIES FOR JOINT ORTHOPAEDIC MEETING OF THE ENGLISH-SPEAKING WORLD

May 11, 1958 through May 16, 1958

(Recommended apparel: Linen, cotton, silk, or very lightweight wool for street wear, together with a lightweight coat, raincoat, sweater, and umbrella)

1. National Gallery of Art (privately conducted tour).
2. Bus tour of Washington (30 miles): a comprehensive tour including Lincoln and Jefferson Memorials, Capitol Hill and the White House.
3. Embassy Tea.
4. White House tour (perhaps privately guided).
5. Smithsonian Institution (privately guided): of special interest is the First Ladies Hall displaying the inaugural gowns of all wives of former Presidents.
6. Luncheon and Fashion Show.
7. Bus tour of Arlington Cemetery (including the change of guards at the Tomb of the Unknown Soldier), Lee Mansion, Marine Retreat at Iwo Jima Memorial.
8. Morning Coffee and Reception honoring wife of the Vice-President and wives from the Embassies of other English-speaking nations: to be held at Dumbarton House, Colonial Dames National Headquarters in Georgetown.
9. Combined boat and bus trip to Mount Vernon, colonial home of George Washington (15 miles down the Potomac River). Return bus trip includes a tour of historic Alexandria, Virginia.
10. Tours (privately guided) of Islamic Center (mosque handsomely decorated with carvings and mosaics done by artisans brought from the Middle East. Gorgeous carpeting). Tour of Washington Cathedral (Episcopal).
11. Bus tour of Capitol Hill, including Capitol Building (with Congress in Session), Supreme Court (also in Session), Folger Library (replica of Shakespeare Theatre), and the Library of Congress.
12. Federal Bureau of Investigation (F. B. I. guided tour).
13. Corcoran Gallery of Art (Exhibit: "Living Today;" good design in contemporary architecture, interior decoration, and furniture in the United States.)

### Other Places of Interest and Special Events

14. National Presbyterian Church (President's Church)—9:00 A.M. Service. Block seating may be reserved for the 9:00 A.M. Service if desired.
15. The Franciscan Monastery—6:00 A.M. and 9:00 A.M. Masses. Church of the Catacombs and Holy Land Shrines (frequently conducted tours).
16. Constitution Hall and DAR Building, containing the famed DAR Early American Museum.
17. Mellon Concert, East Garden Court, National Gallery of Art. Seating is arranged around a beautiful fountain surrounded by flowering trees and plants. (No reserved seats), Sunday, May 11th, 8:00 to 9:30 P.M.
18. National Theatre—8:30 P.M. Monday through Saturday—"No Time for Sergeants."

19. Baseball at Griffith Stadium (8:00 P.M., May 12, 13, 14): Boston Red Sox versus the Washington Senators.
20. Harness Racing at Rosecroft, Oxon Hill, Maryland—nightly. (Group bus transportation can be arranged if desired.)
21. Ford's Theatre (where Lincoln was shot)—now restored and made into a small museum.
22. Treasury Building.
23. Zoological Park.
24. Public tours of Voice of America and U. S. Information Agency.
25. Museum of Natural History.
26. Army Medical Museum.

As part of the Annual Meeting of the **International Academy of Pathology** to be held at the Hotel Statler, Cleveland, Ohio, April 22 and 23, 1958, there will be given a course in Pathological Physiology and Pathology of Bone. Dr. Granville A. Bennett, Dean, University of Illinois College of Medicine, Chicago, Illinois, will be Moderator. The course will include the following:

1. Embryology of Bone. Dr. E. Carl Sensenig, Birmingham, Alabama.
2. Growth of Bone. Dr. Harry Sicher, Chicago, Illinois.
3. Anatomy of Bone. Dr. Ernest Gardner, Detroit, Michigan.
4. Chemical Dynamics of Bone Mineral. Dr. William F. Neuman, Rochester, New York.
5. Organic Composition of Bone. Dr. Melvin J. Glimcher, Boston, Massachusetts.
6. Histology of Bone. Dr. Geoffrey Bourne, Atlanta, Georgia.
7. Histochemistry of Bone. Dr. Reidar F. Sognnaes, Boston, Massachusetts.
8. Relationship of Organic and Inorganic Structure of Bone. Dr. Robert A. Robinson, Baltimore, Maryland.
9. Physiology of Bone. Dr. Franklin C. McLean, Chicago, Illinois.
10. Metabolism of Bone. Dr. Robert D. Ray, Chicago, Illinois.
11. Clinical Significance of Bone Metabolism. Dr. Isadore Snapper, Brooklyn, New York.
12. Effects of Ageing on Bone. Dr. W. Montague Cobb, Washington, D. C.
13. Repair and Regeneration of Bone. Dr. D. Murray Angevine, Madison, Wisconsin.
14. Bone-Grafting. Dr. John Chalmers, Chicago, Illinois.
15. Neurocirculatory Effects on Bone. Dr. Walter G. J. Putschar, Charleston, West Virginia.
16. Nutritional Effects on Bone. Dr. Joseph Wienmann, Chicago, Illinois.
17. Hormonal Effects on Bone. Professor E. A. Uehlinger, Zurich, Switzerland.
18. Radiation Injury on Bone. Mr. Webster Jee, Salt Lake City, Utah.
19. Developmental Diseases of Bone. Dr. Jonathan Cohen, Boston, Massachusetts.
20. Spontaneous Bone Diseases of Animals. Dr. T. C. Jones, Boston, Massachusetts.
21. Pathology of Osteomyelitis. Dr. Golden Selin, New York, N. Y.
22. Neoplasms of Bone. Dr. D. C. Dahlin, Rochester, Minnesota.

## KAPPA DELTA AWARD

The Committee on Scientific Investigation of The American Academy of Orthopaedic Surgeons announces that all manuscripts which are to be entered for the Kappa Delta Award should be forwarded to the Chairman of the Committee, Dr. Robert A. Robinson, The Johns Hopkins Hospital, Baltimore 5, Maryland. The Award, $1,000, is presented annually to any American citizen residing in the United States for the outstanding contribution in the field of orthopaedic surgery. Papers or reports, by eligible persons, published after February 1, 1956, may be considered for the award. The form of the paper should be that required for ethical medical journals printed in the United States. Since the winner of the Kappa Delta Award will present his paper before the general membership of the Academy at the Annual Meeting in January 1959, it is necessary that all manuscripts be received by July 1, 1958, so that they may be properly evaluated and forwarded to the Executive Committee of The American Academy of Orthopaedic Surgeons for approval.

## GORDON RESEARCH CONFERENCES

The Gordon Research Conferences for 1958 will be held from 9 June to 29 August at Colby Junior College, New London, New Hampshire; New Hampton School, New Hampton, New Hampshire, and Kimball Union Academy, Meriden, New Hampshire.

The Conferences were established to stimulate research in universities, research foundations, and industrial laboratories. This purpose is achieved by an informal type of meeting consisting of scheduled lectures and free discussion groups. Sufficient time is available to stimulate informal discussions among the members of a Conference. Meetings are held in the morning and in the evening, Monday through Friday, with the exception of Friday evening. The afternoons are available for participation in discussion groups as the individual desires. This type of meeting is a valuable means of disseminating information and ideas which otherwise would not be realized through the normal channels of publication and scientific meetings. In addition, scientists in related fields become acquainted and valuable associations are formed which result in collaboration and cooperative effort between different laboratories.

It is hoped that each Conference will extend the frontiers of science by fostering a free and informal exchange of ideas between persons actively interested in the subjects under discussion. The purpose of the program is not to review the known fields of chemistry but primarily to bring experts up to date as to the latest developments, analyze the significance of these developments, and to provoke suggestions as to underlying theories and profitable methods of approach for making new progress. In order to protect individual rights and to promote discussion, it is an established rule of each Conference that all information presented is not to be used without specific authorization of the individual making the contribution, whether in formal presentation or in discussion. No publications are prepared as emanating from the Conferences.

Individuals interested in attending a Conference are requested to send their applications to the Director. Each applicant must state the institution or company with which he is connected and the type of work in which he is most interested. Attendance at each Conference is limited to 100.

The complete program of the Conferences was published in *Science* for February 28, 1958.

Requests for attendance at the Conferences, or for any additional information, should be addressed to W. George Parks, Director, Department of Chemistry, University of Rhode Island, Kingston, Rhode Island. From June 9 to August 29, 1958, mail should be addressed to Colby Junior College, New London, New Hampshire.

## GORDON CONFERENCE ON CHEMISTRY, STRUCTURE, AND PHYSIOLOGY OF BONES AND TEETH

### Kimball Union Academy, Meriden, New Hampshire

D. Dziewiatkowski, *Chairman*

Wallace D. Armstrong, *Vice-Chairman*

July 14, 1958
- Elaboration of the Inorganic Structures in Bones and Teeth: Reidar F. Sognnaes, *Chairman*.
    - Fine Structure of the Inorganic Elements in Adult Bones and Teeth. J. T. Albright and Reidar F. Sognnaes.
    - Structural Relationship between Inorganic and Organic Elements in Embryonic Bone. S. F. Jackson.
- Baird Hastings, *Chairman*.
    - The Study of Skeletal Physiology by the Organ Culture Method. Honor B. Fell.

July 15, 1958
- Physics of the Solid State: John H. Marshall, *Chairman*.
    - Dynamics of the Solid State. N. H. Nachtrieb.
    - The Bone Crystal. William F. Neuman.
    - Discussion. A. S. Posner.
- Karl Meyer, *Chairman*.
    - Aspects of the Metabolism of Mucopolysaccharides. Harry Bostrom.

July 16, 1958
- Enzymes of Bone: Alexander B. Gutman, *Chairman*.
    - Active Sulphate and the Synthesis of Chondroitin Sulphate. P. Robbins and F. d'Abramo.
    - Vitamin D and Citrate Metabolism. H. F. DeLuca.
- Franklin C. McLean, *Chairman*.
    - Glycolysis in Epiphyseal Cartilage. Nicolay Egg-Larsen.

July 17, 1958
- Chemistry and Physiology of the Parathyroid Hormone: John E. Howard, *Chairman*.
    - Studies on the Isolation of the Parathyroid Hormone. H. Rasmussen.
    - Physiological Effects of Purified Parathyroid Hormone in Humans.
- E. C. Reifenstein, Jr., *Chairman*.
    - Metabolism of Vitamin D. E. Kodicek.

July 18, 1958
Current Research Trends. Wallace D. Armstrong, *Chairman.*

**La Société Belge d'Orthopédie, la Société Belge de Chirurgie,** and **l'Association Belge de Chirurgie** will hold with **la Société Française d'Orthopédie** a meeting in Bruxelles from May 8 to May 14, 1958.

The next Part II examination of the **American Board of Orthopaedic Surgery** for certification will be held January 21, 22, and 23, 1959, Chicago, Illinois. The deadline for receipt of application is August 15, 1958.

The **Louisiana Orthopaedic Society** met at Point Clear, Alabama, on December 6 and 7, 1957. Duncan C. McKeever, M.D., Houston, Texas, was the guest speaker. The following program was presented:

Congenital Clasped Thumb. Lyon K. Loomis, M.D.
Fractures of the Calcaneus. Open Reduction. A. Scott Hamilton, M.D.
Hip Prostheses and the Mechanical Principles Involved in Them. Duncan C. McKeever, M.D.
Hand Splints. Daniel C. Riordan, M.D.
Presidential Address. T. E. Banks, M.D.
Correction of Paralytic Foot-Drop by Gastrocnemius Soleus Transplant. Gene D. Caldwell, M.D.
Whiplash Injury of the Neck. Duncan C. McKeever, M.D.
Amputations for Peripheral Vascular Disease. Edward T. Haslam, M.D.
Diagnosis of Hand Lesions. Daniel C. Riordan, M.D.
Indications for Lower Extremity Bracing in Cerebral Palsy. Daniel M. Kingsley, M.D.

## THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

At the Annual Meeting of The American Academy of Orthopaedic Surgeons held in New York City, February 1 to 6, 1958, the following men were inducted into membership:

James P. Ahstrom, Jr., Oak Park, Illinois
Joseph Alper, New York, N. Y.
George B. Ambrose, New York, N. Y.
Martin V. Atchison, Harlingen, Texas
S. Pearson Auerbach, Louisville, Kentucky
Thomas C. Baker, Lansing, Michigan
Myron Bash, Trenton, New Jersey
James Gordon Bateman, Long Beach, California
Cyril Joseph Bellavance, Providence, Rhode Island
Ritchie H. Belser, Charleston, South Carolina
Morley L. Bernstein, Niagara Falls, New York
John B. Blakely, Pittsburgh, Pennsylvania
John Franklin Boyd, Albuquerque, New Mexico
James B. Brandon, West Palm Beach, Florida
Robert J. Burleson, Asheville, North Carolina
Henry S. Burlington, Bethlehem, Pennsylvania
Murray E. Burton, New York, N. Y.
Edward Francis Cadman, Wenatchee, Washington
Rolla Dacres Campbell, Jr., New York, N. Y.
Charles O. Carothers, Cincinnati, Ohio
Russell M. Cashen, Kalamazoo, Michigan
William Catalona, Muscatine, Iowa
Lt. Col. George H. Chambers, Scott Air Force Base, Illinois
Baxter L. Clement, Red Bank, New Jersey
Jonathan Cohen, Boston, Massachusetts
Samuel S. Cohen, New York, N. Y.
Marshall Baker Conrad, Clayton, Missouri
James B. Dalton, Jr., Richmond, Virginia
John L. Danielson, Pasadena, California
Richard Lloyd Davis, Salinas, California
James R. Degge, Eugene, Oregon
Michael A. DiCosola, Sarasota, Florida
James Robert Dineen, Corning, New York
James Harold Dobyns, Wood-Ridge, New Jersey
Captain Robert C. Doolittle, Castro Valley, California
Joseph A. Drazek, Detroit, Michigan
Arthur J. Driscoll, Bristol, Connecticut
Marvin H. Dubansky, Des Moines, Iowa
Comdr. Adolphus W. Dunn, % F.P.O., San Francisco, California
Leonard A. Dwinnell, Spokane, Washington
Trinidad R. Edwards, New Orleans, Louisiana
Comdr. Harry B. Eisberg, Portsmouth, Virginia
Comdr. Henry R. Ennis, Charleston, South Carolina
John O. Esslinger, Birmingham, Michigan
Ernest B. Evans, Galveston, Texas
Walter Feinstein, Beverly Hills, California
Carl Martin Fellhauer, Clayton, Missouri
William B. Fischer, Chicago, Illinois
Irving E. Fixel, Hollywood, Florida
James J. Flaherty, Peoria, Illinois
William C. Francis, Springfield, Missouri
Joseph George Furey, Cleveland, Ohio
William F. Gallivan, Jr., Knoxville, Tennessee
Alexander Garcia, New York, N. Y.
Park W. Gloyd, Seattle, Washington
Peter B. Golden, Madison, Wisconsin
John O. Goodsell, Saginaw, Michigan
John T. Grady, Cambridge, Massachusetts
William T. Hall, Riverside, California

Adolph E. Harer, Cameron Village, Raleigh, North Carolina
Hugh B. Haston, Jr., Jacksonville, Florida
Cyril H. Hauser, Winnetka, Illinois
Hugh Hayford, Jr., Altoona, Pennsylvania
David B. Heller, Dayton, Ohio
Charles R. Hoffman, Louisville, Kentucky
Lucius C. Hollister, Jr., Quincy, Illinois
Richard D. Hoover, West Palm Beach, Florida
Harold R. Horn, Jr., Lincoln, Nebraska
David B. Horner, Inglewood, California
James R. Horst, Los Angeles, California
William P. Horton, Baltimore, Maryland
John A. Hunter, Jr., Portsmouth, New Hampshire
Paul F. Hutchins, Jacksonville, Florida
George A. Hyder, Lawrence, Massachusetts
Thomas R. Ivers, Ukiah, California
William E. Jensen, San Francisco, California
Wiley J. Jinkins, Jr., Galveston, Texas
Richard J. Johnson, St. Paul, Minnesota
William E. Johnson, Salem, Massachusetts
Everett Davis Jones, Baltimore, Maryland
James B. Jones, Lynchburgh, Virginia
Lynn Keys, Woodland, California
Nephi K. Kezerian, Provo, Utah
Robert T. King, Mobile, Alabama
Raymond L. Knight, Visalia, California
Leo J. Koven, Brooklyn, New York
Leon M. Kruger, Springfield, Massachusetts
John W. Lachman, Philadelphia, Pennsylvania
Edward B. Leahey, South Nyack, New York
Samuel G. Levin, Brooklyn, N. Y.
Charles W. Linart, Syracuse, New York
Francis T. Linder, New York, N. Y.
Eli M. Lippman, Baltimore, Maryland
Lynn O. Litton, Kansas City, Kansas
Joseph K. Maloy, Boston, Massachusetts
James C. Marr, Jr., San Rafael, California
James H. Masterson, Arlington, Virginia
Thomas J. Masterson, Norwich, Connecticut
Nathan Meadoff, Bakersfield, California
Chester K. Mengel, Muskogee, Oklahoma
Elwin W. Midgley, Vallejo, California
Lee Watson Milford, Jr., Memphis, Tennessee
Alfred M. Mintz, Hammond, Indiana
Arthur E. Mittnacht, Princeton, New Jersey
William L. Moffatt, Jr., Memphis, Tennessee
Antonio E. Molina-Rivera, Miami, Florida
Roscoe S. Mosiman, Seattle, Washington
Neil P. McCloy, San Francisco, California
Bernard E. McConnell, Greenville, Texas
Edward W. McLoone, Phoenix, Arizona
William E. Nelson, Downey, California
George Quayle Neslen, Whittier, California
William H. Newman, Chicago, Illinois
Max M. Novich, Newark, New Jersey
Harrison J. O'Connor, Champaign, Illinois
Robert R. Oden, Aspen, Colorado
Paul K. Odland, Janesville, Wisconsin
Joseph P. Ostrowski, Rome, New York
Philip J. Palazzo, New York, N. Y.
Jerome F. Paulson, Mason City, Iowa
Martin W. Payne, Las Vegas, Nevada
Leonard F. Peltier, Kansas City, Kansas
Thad W. Penn, Waukegan, Illinois
William H. Penninger, Springfield, Missouri
Myra Ann Peters, Tulsa, Oklahoma
James J. Pollex, Jr., Toledo, Ohio
Dale D. Popp, Spokane, Washington
Captain John J. Price, Jr., Oakland, California
Charles E. Ratcliff, Lubbock, Texas
Earl J. Rhoades, New Haven, Connecticut
John Ricker, Phoenix, Arizona
Herman Robbins, New York, N. Y.
James G. Roberts, Akron, Ohio
Cecil A. Robinson, Kermit, Texas
Joseph O. Romness, Washington, D. C.
Lt. Col. Adolphe J. Schoepflin, Fort Leonard Wood, Missouri
Albert A. Schwartz, Perth Amboy, New Jersey
James Walter Shuffield, Jr., Beaumont, Texas
William Anthony Sinton, Danbury, Connecticut
Garland F. Smith, St. Louis, Missouri
Harold Osborne Smith, Flint, Michigan
George James Solas, Fall River, Massachusetts
George Edward Spencer, Jr., Cleveland Heights, Ohio
Clair T. Steggall, Fresno, California
Lorin L. Stephens, Arcadia, California
Myer Stumer, Michigan City, Indiana
Dan R. Sutherland, Dallas, Texas
Irvin I. Taitz, East Orange, New Jersey
Joseph Blaine Tanner, Palo Alto, California
Andrew H. Thomas, Manchester, Connecticut
Carruth J. Wagner, Washington, D. C.
Sidney C. Walker, Port Huron, Michigan
L. Scott Wallace, Beaumont, Texas
William J. West, Dayton, Ohio
William R. Willis, Orlando, Florida
Russell Nick Worobec, Sayre, Pennsylvania
Charles Stewart Wright, Toronto, Ontario, Canada
John Gantt Yost, Hastings, Nebraska
U. A. Young, Tampa, Florida
Horace I-Sen Yu, New York, N. Y.
Morris M. Zack, Beverly Hills, California

# Book Reviews

THE CHEMICAL DYNAMICS OF BONE MINERAL. William F. Neuman and Margaret W. Neuman. Chicago, The University of Chicago Press, 1958. $5.00.

This unique book was written by a couple with outstanding reputations in research in bone chemistry to try to evolve reasonable explanations of some of the most perplexing problems of physiology. Their effort, deserving high praise, is a delightful and successful mixture of erudition and speculation. Anyone who has tried to understand the data on which the experts base their opinions concerning the undersaturation or supersaturation of serum with respect to calcium or phosphate, or concerning the ways by which vitamins or hormones can affect the ion concentrations in serum, or concerning a thousand other questions vital to the understanding of bone physiology will appreciate the frank interpretive treatment by two experts of most of the available data. They state in their introduction that this book is an attempt at a general synthesis which encountered "a severe shortage of good building material—established experimental results;" thus preliminary findings and speculation served as substitutes. They are meticulous in designating material as fact, preliminary findings, or fantasy.

The contents of the book center around the inorganic crystals of bone, their surface chemistry, the principles underlying their formation, size, and composition, the laws of solution chemistry applicable to their relations with surrounding fluids, and the role of the different ions in the solution in the formation of the solid phase. Consideration is also given to the new tools used to clarify dynamic aspects of bone physiology, such as the pool concepts, the limitations of tracer experiments, and the possible participation of hormones or vitamins in metabolic pathways involving citrate or other carbohydrate synthesis.

Many readers will be intrigued by the good sense and straightforward approach in the preface and in the opening portion of the book. Those whose scientific training dates back fifteen years or more may then be discouraged by the more sophisticated formulation needed for exposition of such concepts as activity coefficient or, further along, by other chemical concepts such as recrystallization, and by the kinetic analysis of dynamic models. Such readers may pass over these more complicated sections, which in any case do not take up a very large part of the book, in order to arrive at the essential parts, which in my opinion, are easily comprehensible to nearly all of those interested in bone physiology.

The sections on inorganic chemistry and crystal structure are especially clear in the way they resolve many of the apparent contradictions of data in the literature. The section on physiology is somewhat less clear for two reasons: (1) the subject is so much more complicated, and (2) the authors allow themselves a greater latitude in speculation in this area.

The authors state that this book probably will not remain modern very long because experimental facts will undoubtedly alter the directions of speculation. Nevertheless, the book has timely considerations of nearly all the data available at present ana while it does not attempt to review other speculations on the data which are in some disagreement with those of the authors, it does present a tenable point of view.

The style of the authors is conversational—often refreshingly so. An experimental flop is so designated. At one point, the authors "skate on thin ice" and then "walk on water." However, their book may best be described, in all senses of the term, as "solid."

*Jonathan Cohen, M.D.*

THE FOREQUARTER AMPUTATION. H. F. Moseley, M.A., D.M., M.Ch. (Oxon.), F.R.C.S. (England and Canada), F.A.C.S. Philadelphia, J. B. Lippincott Company, 1957. $10.00.

This volume is a scholarly addition to the several previous delightful monographs and films which Dr. Moseley has produced on the anatomy and pathological conditions of the shoulder region. It will be welcomed by bibliophiles and students.

A painstaking review of the literature, going back to the first recorded case in 1737, is one of the interesting features of this presentation. These early case histories reflect the surgical practice of the times. The earliest are records of avulsion injuries and gunshot wounds. The vessels were usually torn, retracted, and closed by spasm. There was little hemorrhage and not too much shock despite the extensive injuries. For the most part, treatment was by dressings alone, or dressings combined with adjustment of the skin edges, sometimes with suture. In a few instances ligature of vessels is mentioned. In 1866 chloroform was administered to two patients during operation, in 1869 the wound was dressed with carbolic acid solution (1:40), and in 1876 skin-grafting is reported.

The courageous performance of several formidable procedures by our early forebears in surgery and their great contribution is noted. Dr. Dixi Crosby, Professor of Surgery in the Dartmouth Medical College, did the initial recorded, planned, successful scapulothoracic amputation for "osteo-sarcoma" in 1836. In the following year, removal of the scapula and clavicle for a recurrent chondroma was reported.

The anatomy of the scapulohumeral area is delineated in detail and is shown in a series of beautiful color plates. A separate group of plates is used to illustrate the step-by-step operative technique of forequarter amputation by the anterior and posterior approaches, of scapulectomy, and of resection of the scapula, the outer clavicle, and the upper portion of the humerus.

The indications for these procedures are briefly reviewed. Prosthetic replacement and rehabilitation are mentioned.

*Robert Mazet, Jr., M.D.*

Artificial Limbs. Leon Gillis, M.B.E., M.B., B.Ch., M.Ch. Orth., F.R.C.S. London, Pitman Medical Publishing Co. Ltd., 1957. £15.0.0.

The author presents an interesting and instructive study of the problems associated with artificial limbs. The material of the book is a compilation of information acquired over the years from the experiences of the author, of his colleagues, and of many technicians and fitters, and from the literature. The book is divided into three sections.

The first section is devoted to limb-fitting. In this section the relationship of the modern amputation stump to artificial limbs is stressed. The anatomical principles involved in the planning and fitting of prostheses, the physiological problems, the history of artificial limbs or prostheses, and the clearly defined requirements of the modern prosthesis are also dealt with.

The second section is on artificial limbs. Here the author discusses in a most interesting manner the construction of the mechanical joint, the upper- and lower-extremity artificial limb, and the mechanical hand. Various aspects of prosthetic research are also dealt with.

The third section is entirely devoted to rehabilitation. Here are discussed natural and prosthetic gait, training in the use of artificial limbs, psychosomatic approach to the problems of the amputee, social welfare and resettlement of the amputee, and, finally, the assessment of disability.

The three sections are profusely illustrated and contain extensive bibliographies.

This is a thorough and complete work on artificial limbs. To use the words of Sir Harry Platt in the Foreword, "Mr. Gillis has once more rendered a great service to this most deserving section of human society."

*John Royal Moore, M.D.*

Training of the Lower Extremity Amputee. Donald Kerr, B.B.A., and Signe Brunnstrom, M.A. Springfield, Illinois, Charles C. Thomas, 1956. $6.50.

This is a manual of procedures essential in the training of various amputees in order to achieve the functional potential in each particular instance.

The instructions are clear, concise, sequential, and adaptable to various situations. They cannot fail to lead to a higher level of achievement than many amputees may believe possible.

There is some question as to the audience the book will most profit. The jacket addresses it equally to the surgeon, nurse, physical therapist, limbmaker and amputee, and doubtless, all will benefit. In the Introduction, Dr. T. Campbell Thompson recommends it to all amputees, and to all others interested in amputee rehabilitation. The authors address it to the several members of an amputee team and secondly, hope that many amputees will find it useful.

The account ranges from the problems of adjustment of the patient (and his total environment) to the amputation, to procedures in selected cases leading to exceptional skills. It is so excellent that there is little to criticize. However, it is suggested that line drawings showing how to bandage stumps were unwisely omitted in favor of referring to an article. Further, many times a mid-thigh amputation is referred to as "the best site" (page 114) and only once (page 64) is a longer thigh stump considered as also "most favorable." This seems the more remarkable since the paragraph heading, page 114, is "Proper Shape and Length of Stump."

To those who have watched the "performers" at teaching clinics walking when off guard, it may seem that some of the standards of performance are somewhat unrealistic although generally statements are fairly qualified. However, this, and some doubt as to the advantage to many amputees of "going by the book" would cause the reviewer to be quite selective as to which of his patients he would give the book.

This reviewer believes the book will find its greatest usefulness in the office of the surgeon performing occasional amputations and who, of necessity, is his patient's chief hope, other than the limbmaker. There must be few of us who could not study this manual without benefit.

*Vernon P. Thompson, M.D.*

Die Hüftnahen Femurosteotomien. Unter Berücksichtigung dep Form, Funktion und Beanspruchung des Hüftgelenkes. Dr. Maurice Edmond Müller. Stuttgart, Georg Thieme, 1957. DM 49.50.

This volume consists essentially of two separate monographs: (1) a section sixty-five pages long in which general considerations are discussed and (2) a section of 106 pages devoted to a study of 297 cases of various hip disabilities, mainly congenital dislocations, treated by intertrochanteric osteotomy.

Twenty-five pages of the first section are devoted to a description of the use of Dr. Müller's roentgenischiometer. This is a gadget modeled on Wiberg's instrument to measure the CE angle. By making roentgenograms in two special positions the author asserts that it is possible to measure not only the CE angle of Wiberg but also the angle of the femoral neck, the length of the femoral neck, the angle of anteversion, the center of the femoral head, the center of the acetabulum, and the direction of the femoral neck. This information appears to be of some interest with respect to the diagnosis of congenital dislocation of the hip, but it bears no relationship to the main topic of the volume—osteotomies of the upper end of the femur. There is much information that is interesting but entirely gratuitous, and the relationship between the form, function, and internal architecture of the upper end of the femur is handled in a most superficial manner.

The larger second section of the work encompasses a study of 232 intertrochanteric osteotomies performed for different conditions involving the hip joint: congenital dislocation of the hip (150 intertrochanteric osteotomies), epiphysolysis, arthritis of the hip, and paralysis.

Although the author describes what are now known as derotation, angulation, and transposition osteotomies, all must be included in the single category of intertrochanteric osteotomies of a directional nature. Unfortunately however discussion of the type of osteotomy which Pierre Marie Lance has so aptly denominated as the pelvic-support osteotomy has been entirely overlooked.

This is the more regrettable since it necessarily omits consideration of many topics which are among the most interesting associated with osteotomy of the upper end of the femur. The significance of the femoral neck, the mechanism of action of the pelvic-support osteotomy, and the effect of such osteotomies on the kinesiology of the pelvis are quite as important and far more interesting than a consideration of the application of the directional intertrochanteric osteotomy in the treatment of a number of different clinical conditions. The late results of the various procedures are not of course available since the procedures were performed between May 1952 and the end of 1955. Consequently, the author's opinion as to the success of this treatment on the coxarthroses and paralyzed hips cannot be accurately evaluated.

Apart from this it is not always clear to which cases the excellent roentgenographic reproductions refer, nor indeed whether the serially numbered roentgenograms always refer to the same patient.

At the end of the volume a large number of references, well organized with respect to the individual chapters, is appended.

*Henry Milch, M.D.*

ORTHOPEDIC SURGERY IN INFANCY AND CHILDHOOD. Albert Barnett Ferguson, Jr., M.D. Baltimore, The Williams and Wilkins Company, 1957. $15.00.

This fine book presents a vast collection of material portraying orthopaedic entities and operations of infancy and childhood. The numerous illustrations and the quality of their reproduction are in keeping with the other outstanding physical qualities of the book.

In the first section of the book, the subjects are divided on an anatomical basis and present material on the foot, knee, hip, spine, neck, and upper extremities. The second portion of the book is composed by subject. The mixed arrangement of the material on both an anatomical and entity basis makes finding all of the material on a given subject a little difficult. However, the index is comprehensive and well organized. Two contributors share in the anatomical portion of the book: John S. Donaldson and Frank H. Stelling. The large and well presented chapter on affections of bone is written by Albert B. Ferguson, Sr. and Robert Klein. The subjects of amputations, prosthetics, and rehabilitation techniques are conspicuous by their absence. The chapters on bone tumors and scoliosis leave the authors further opportunity to extend themselves in another edition. Fractures are not discussed, the reader being referred to Blount's *Fractures in Children*. It is not to be expected that every section in such a textbook would be outstanding. The shortcomings in this book are those inherent in a textbook and are far outweighed by the attributes. Many of the concepts of Dr. Ferguson's teachers (Joseph S. Barr, William T. Green, and Albert B. Ferguson, Sr.) are clearly reflected. This treatise can be recommended with enthusiasm for orthopaedic surgeons and paediatricians, young and old.

*J. Vernon Luck, M.D.*

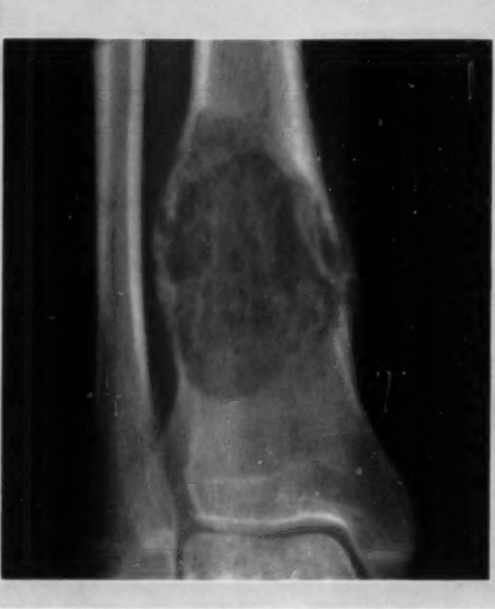
THERAPEUTIC EXERCISE FOR BODY ALIGNMENT AND FUNCTION. Marian Williams, Ph.D., and Catherine Worthingham, Ph.D. Philadelphia, W. B. Saunders Company, 1957. $3.50.

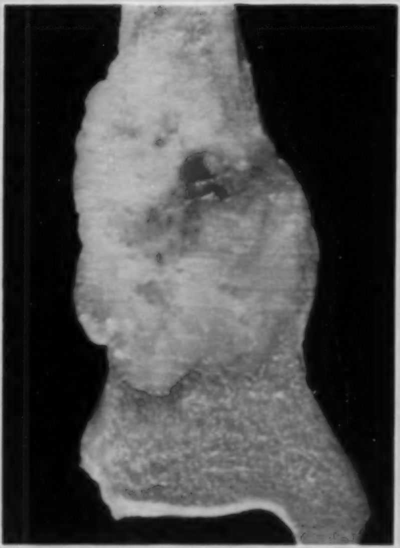
This well illustrated manual is designed to show the techniques and positions of various exercises. It does not attempt to correlate the exercises with specific pathological entities and, thereby, avoids many of the pitfalls of other books on the subject.

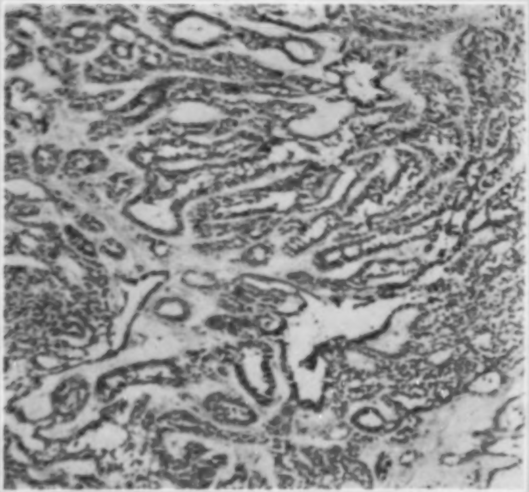
There is a brief introduction on the principles of body exercise which is confined to the mechanical concept of gravity; it does not touch on muscle physiology or the like.

In short this manual is of value to the physical therapist and the physical-education instructor in learning the details of specific exercises. It may be helpful to the orthopaedic surgeon in reviewing specific exercise techniques.

*J. T. H. Johnson, M.D.*







## ADAMANTINOMA . . . 3 aspects

**Radiograph** *(upper left)* showing an adamantinoma in the lower end of a tibia in a man of 48 years. The lesion has caused lytic destruction and expansion of the contour of the affected part of the bone.

**Photograph** *(upper right)* of frontal section of specimen. The adamantinoma tumor tissue was clearly demarcated from the spongiosa. It was tough and firm but presented small areas of cystic degeneration.

**Photomicrograph (x 90)** *(left)* showing the alveolar glandular pattern so characteristic of certain fields of an adamantinoma.

Turn page for data on Osteogenic Sarcoma.

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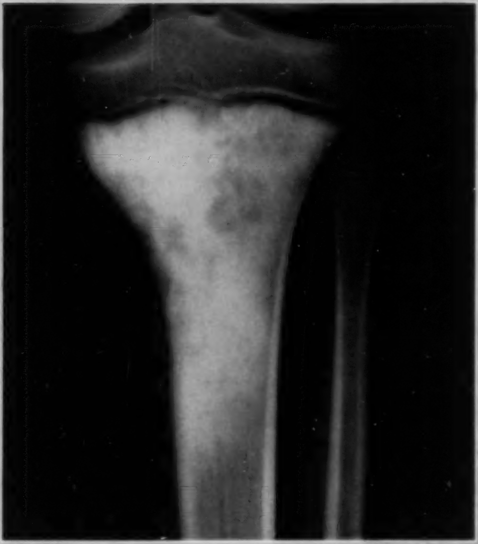

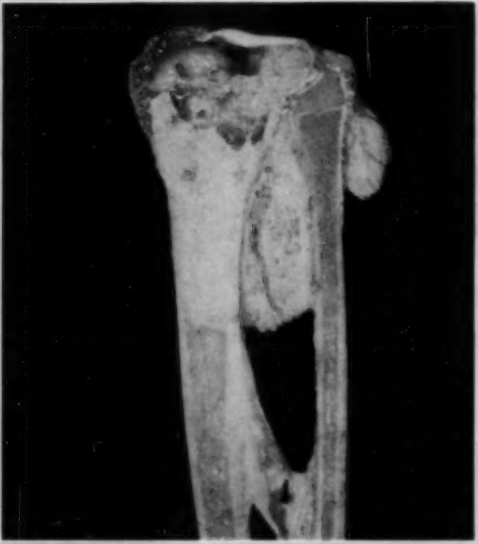

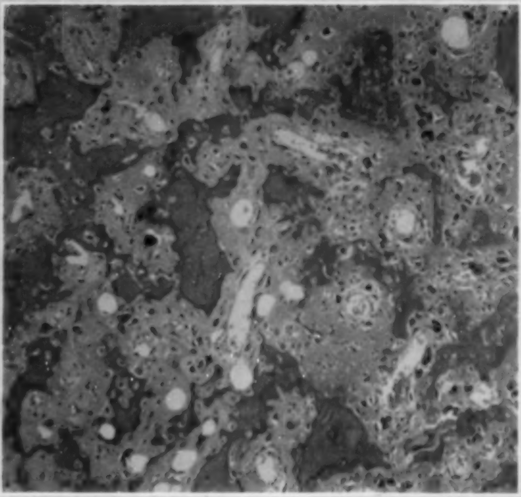

## OSTEOGENIC SARCOMA . . . 3 aspects

**Radiograph** *(upper left)* of a highly ossifying osteogenic sarcoma in the upper part of the shaft of tibia of a boy of 10 years.

**Photograph** *(upper right)* of longitudinal section of tibia shown in radiograph above. Part of the cortex and epiphyseal plate have been destroyed, but the epiphysis is still not invaded.

**Photomicrograph (x 70)** *(right)* showing an osteogenic sarcoma tissue field in which a considerable amount of calcifying intercellular material has been laid down between the tumor cells.

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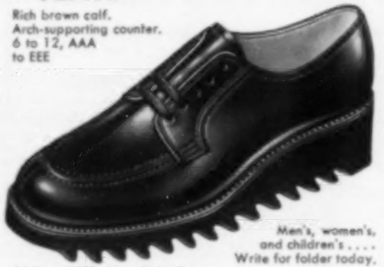

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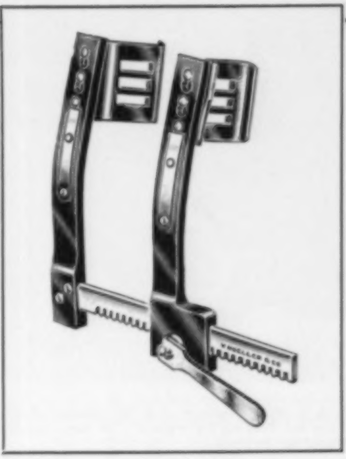

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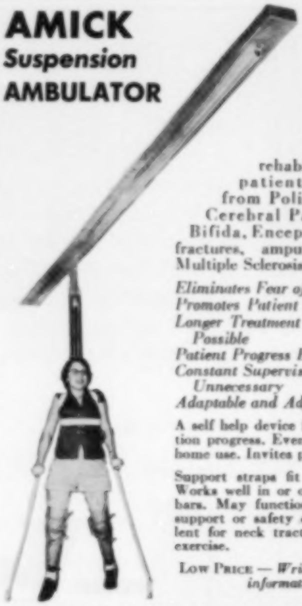

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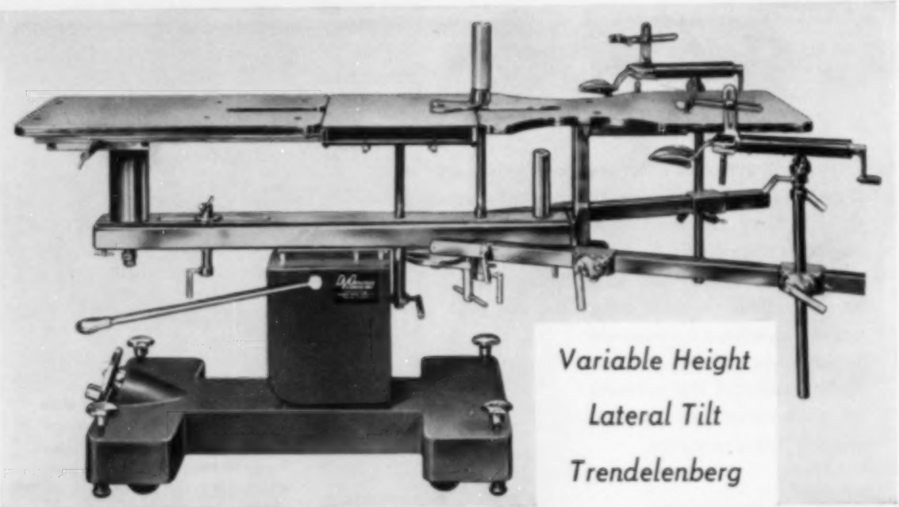

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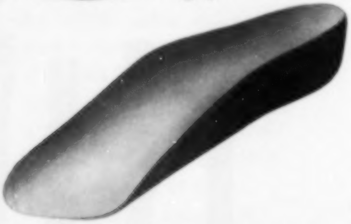

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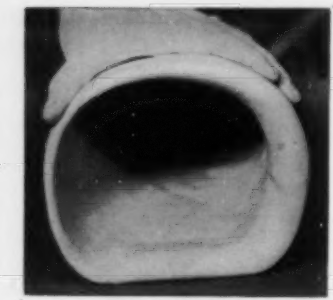

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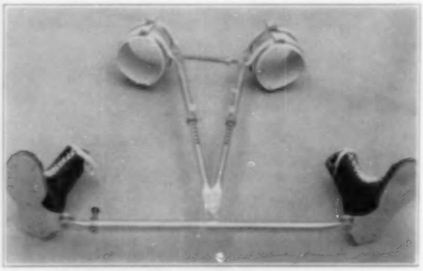

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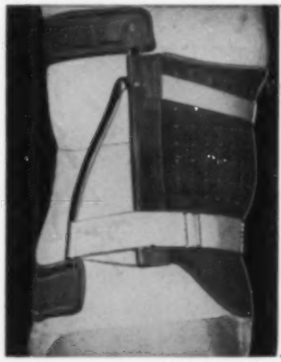

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